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THE RELATIONSHIPS OF THE BASE OF THE MISSISSIPPIAN SYSTEM IN MISSOURI[1]

MAURICE G. MEHL[2]

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[1] A Progress Report, published with the permission of the State Geologist of Missouri.

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ILLUSTRATIONS

INTRODUCTION AND ACKNOWLEDGMENTS

In 1954 E. L. Clark, then State Geologist of Missouri, suggested that I utilize such time as could be spared from my regular duties at the University of Missouri to investigate the status of the "Sylamore" and "Bushberg" in Missouri, along with other problems that might develop from these investigations. During the early part of the field work directed toward that end I profited greatly by the association with Thomas R. Beveridge who later succeeded Clark as State Geologist.

Early in the investigations the objectives became more clearly defined and were thought of as the multi-faceted problem of the relationships of the base of the Mississippian System in Missouri. To complete any one of the many problems that developed might well require many months, and to complete all appeared beyond the reach of a single worker. It was decided recently that a summary of the considerable volume of data accumulated would help minimize duplication of efforts among other researchers. It was also hoped that in such a summary there could be established a broad framework of reference into which ultimately might be fitted the many parts. Certainly the project will benefit by suggestions from and criticism by other investigators. It is with this in mind that I submit this progress report.

Not only has the financial support of the Missouri State Geological Survey made this work possible, but individual members of the Survey have helped in the field and have given advice on problems of procedure. Foremost among these are Thomas R. Beveridge, John W. Koenig, Wallace B. Howe, and James A. Martin. Richard B. Aylor, Geologist for the Missouri State Highway Department, has given me much valuable information concerning new exposures in the

quarries and the highway cuts within the state. Many graduate students in the Department of Geology at the University of Missouri have contributed much during the past several years. George H. Fraunfelter is given special mention for his invaluable assistance in the field and in the laboratory. I acknowledge with great pleasure the interest of my colleague, Clayton H. Johnson, who has often helped in deciphering field data and has made many helpful suggestions at all stages, particularly in the preparation of the manuscript.

I cannot overemphasize the fine cooperation of the Department of Geology at the University of Missouri which has given me every possible assistance in the way of laboratory materials, working facilities, and personal services.

PART I

THE DEVONIAN-MISSISSIPPIAN BOUNDARY IN NORTH AMERICA

Solution of the problems involved in drawing the boundary between the Devonian and Mississippian Systems in North America has progressed slowly since the first recognition of Devonian sediments on this continent. Actually, with closer stratigraphic discrimination, new problems seem to have arisen more rapidly than solutions have been found. A comparison of two of the more recent comprehensive correlation charts emphasizes the fact that the picture of this boundary is still much confused. In the first of these, "Correlation of the Devonian sedimentary formations of North America" (Cooper et al., 1942), the Bushberg of Missouri is placed in the Mississippian; and the Glen Park, Louisiana, Grassy Creek, and Sylamore in the Devonian. In the second chart, "Correlation of the Mississippian formations of North America" (Weller, J. M. et al., 1948) the Kinderhook formations are divided into two groups, the Easley group above to include "all Kinderhook strata which are almost universally recognized to be of Mississippian age", and the Fabius group below consisting "of those Kinderhook strata which are believed by some to be Mississippian but by others to be Devonian". In Missouri the Fabius includes the Louisiana, Saverton, Grassy Creek, and Sylamore. The Bushberg is placed in the Easley group.

Data bearing on Devonian-Mississippian relationships in Missouri, as presented in the present study, are graphically summarized in Figure 8, p. 104.

Students of stratigraphic paleontology are not disturbed greatly by these incongruities in interpretation. They recognize that the majority of the Devonian-Mississippian "boundary" formations record environments that were hostile to many of the invertebrate groups that have been most useful in close stratigraphic determinations. The meager fauna found in most of these formations is neither typically Devonian nor Mississippian, and the worker is called upon to decide which of the two ages it most nearly resembles. It follows that the same material in the hands of one worker places the formations in the Devonian and in the hands of another assigns these formations to the Mississippian. Unfortunately, this shifting of age assignment among the boundary formations seems to be one factor that has led to the concept that the Devonian-Mississippian transition is a zone of gradation rather than a boundary in the ordinary sense.

Another factor, apparently working toward the same end comes from the nor-

mal refinement of stratigraphic studies, the ultimate discovery of contradictory data in the several parts of the originally named unit. The history of the New Albany shale studies illustrates the point. Named by Borden (p. 158), the New Albany came to be known as a predominantly black fissile shale succession above Middle Devonian (Hamilton) limestone and beneath the Rockford (Mississippian) limestone.

The first comprehensive study of the fauna was that by Huddle (1934). He described a considerable variety of conodonts from the lower, middle and upper parts of the shale and decided (with some reservations) that all were Devonian. Later Branson and Mehl (1941, pp. 201–204) studied conodonts from the upper part of the New Albany and considered them to be indisputably Mississippian in age. Most of these had been described and figured by Huddle from what he designated as the upper conodont-producing zone. Campbell (p. 855) restricted the New Albany by designating the "nine inches of soft greenish to dark green glauconitic, sparsely fossiliferous shale" beneath the Rockford as the Jacobs Chapel formation. He divided the thus restricted New Albany into three parts that roughly correspond to Huddle's lower, middle and upper conodont-producing zones. The lower two zones, the Blocher and the Blackiston formations, were assigned to the Devonian. The third, Campbell's "upper New Albany", consists of the Sanderson followed by the Underwood and Henryville. According to Campbell, Mississippian conodont fauna was introduced at the beginning of the Sanderson time.

Campbell's statement, as here quoted (pp. 855, 904), leaves no doubt concerning his interpretation of the nature of the Devonian-Mississippian boundary in the New Albany.

> Thirty-three Devonian species occur in the middle of the Sanderson which should represent a pure Sanderson assemblage . . . Stratigraphic admixture does not explain the presence of species common to the Blocher and of eight common with the Rhinestreet. There was no advance of the sea that would give opportunity for the admixture after the beginning of the Sanderson, in fact the sea was regressive during the latter part of the New Albany. It appears that the Devonian species were present in the Mississippian upper New Albany as part of their range.

And again:

> The probable synchronous development of the latest Devonian and earliest Mississippian life in separate basins has long been recognized, but the conditions in the Sanderson— show the arrival of Mississippian forms and their continued existence among Devonian species—

It is evident from the above that Campbell's concept of the various factors contributing to conodont admixtures is very different from that of many students of conodonts. Very likely many stratigraphers will continue to speak of "The New Albany, in part Mississippian and in part Devonian", along with the implications that this carries.

COMPARISON OF THE DEVONIAN-MISSISSIPPIAN TRANSITION IN EUROPE WITH THAT IN NORTH AMERICA

It is conventional to divide the upper Devonian of Central Europe, the Frasnian and Famennian, into five zones, *to*I, *to*II, etc. Likewise, the lower Mississippian Tournaisian and the Visean are divided into zones designated, from oldest to youngest, *cu*I, *cu*II, *cu*III, etc. This zoning is based primarily on ammonoid distribution data and has the unqualified acceptance of most stratigraphers. On this basis certain world wide correlations have been made, including the identification of a considerable number of these zones in North America.

In Europe no strong evidence of a marked break in the continuity of the Devonian-Mississippian life succession has been noted. It follows that the gross similarities between the North American column and that of Europe give support to the concept of "gradational transition" in North America. However, it should be pointed out that the European Upper Devonian zones, *to*IV and *to*V, have not been identified in North America. Furthermore, the picture of the European succession of Devonian-Mississippian conodonts is very different from that of other major groups as will be shown presently. A point that cannot be overemphasized is that most of the "boundary formations" in North America, particularly in Missouri, seem to fall in the interval between the European *to*III and *cu*II.

Evidence of the Conodonts

Early in their work with conodonts Branson and Mehl saw in the Upper Devonian assemblages a markedly diversified fauna with the component elements falling into two distinct groups. One might be designated as long range paragenera, abundantly represented in both Devonian and Mississippian strata. The other, the "marker" group, includes such paragenera as *Icriodus*, *Palmatolepis*, *Polylophodonta*, *Nothognathella*, *Apatognathus* and others. These, abundantly represented in the Upper Devonian, were not correctly recorded (indigenous) in any strata of undoubted Mississippian age. Another considerable group of very distinct paragenera, not found in any sediments of undisputed Devonian age, were well represented in the oldest sediments of undisputed Mississippian age. This break in conodont history was pointed to as one of "the greatest gaps in the history of conodonts" (Branson and Mehl 1938B, p. 128), a concept very different from the generally accepted "gradational transition" from the Devonian to the Mississippian.

Since the idea of this "great gap" was first proposed, an increasingly important mass of data on conodont distribution has been accumulated in both North America and Europe, all pointing toward a sharp boundary between the Devonian and Mississippian systems rather than a gradual transition. The validity of these observations is dependent entirely on how "admixture" as opposed to indigeniety is determined. The principles of admixture were discussed at some length by Branson and Mehl (1941, pp. 195–199); and more recently the subject was thoroughly reviewed by Müller (1956, pp. 1338, 1339).

Upper Devonian and Lower Mississippian Conodonts in Europe and North America

It is difficult to translate North American conodont distribution data into the framework of European stratigraphic classification without implying correlations that may or may not be justified. However, disregarding the obvious difficulties involved and the imminent possibilities of misinterpretation, there are arranged in the accompanying chart (Fig. 1) several of these Devonian and Mississippian conodont "markers" in a manner calculated to focus attention to similarities and differences in the Devonian-Mississippian boundary in Europe and North America.

It is evident that in constructing the chart all of the considerable number of paragenera that are to be found in both the Devonian and Mississippian have been omitted. Of those forms that do not "cross the line" in America only those groups that are well represented in both continents and are so distinctive that there is but slight chance of misidentification have been selected. Several forms like *Polylophodonta* are omitted because they are well represented in one continent only. Paraspecies have been ignored, with one exception, because it is felt that we still have much to learn about conodont speciation procedure. This exception, the "*P.* linguiformid group", refers to a group of Polygnathid species of which *P. linguiformis* is typical. The data for European distribution have been gathered from several sources, but chiefly from the work of Bischoff, Bischoff and Ziegler, Müller (1956A), Sannemann, and Vosges.

In the Devonian sections of the chart the lower range is not necessarily accurate; it is the upper range that is important. On the North American side of the chart the upward range is not calculated to mark a time zone, but to indicate only that all members of the group were present at the time of disappearance of the fauna. It does suggest a hiatus of considerable magnitude. Similarly, it is the lower range of the group in the Mississippian sections that is important; the upper range is approximate.

The most striking aspect of the chart is the fact that, with one exception, no group crosses the line between Devonian and Mississippian "markers". The exception, *Pseudopolyghathus*, has not been found in any formation of undisputed Devonian age in North America, but it is very abundant in the oldest of the undisputed Mississippian. On the other hand, there can be no question of its identification in zone *to*V and possibly also in *to*IV in Europe. This suggests an appreciably greater hiatus in North America between the two systems than in Europe with the possibility that *to*V and even *to*IV may not be represented in North America. This must be interpreted either as delayed migration or the absence of recording media in North America equivalent to the European *to*V. In the light of other distribution data the latter interpretation is more inviting. This finds support in Müller's statement (1956C), "Conodonts from equivalents of the Oxyclymenia-Stufe and Wocklumeria-Stufe are not known from North America".

Two forms, *Doliognathus* and *Scaliognathus*, are included in the chart although they have no direct bearing on the "boundary line" problem. These two paragenera are easily identified and are abundantly represented on the two conti-

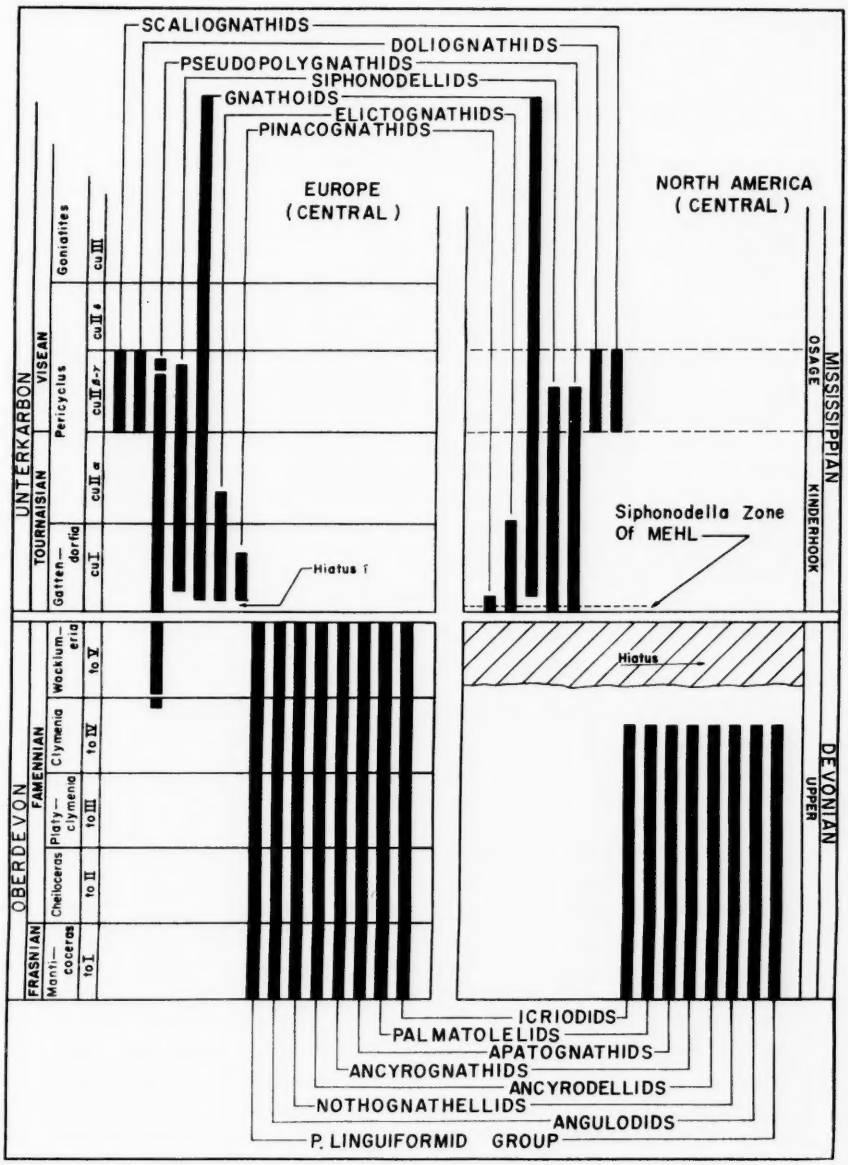

FIG. 1. Vertical range of selected Mississippian and Devonian conodont "markers" in Europe and in North America. For an explanation of the construction of the chart and aid in its interpretation see details in the text.

nents. Their vertical range seems to be sharply defined in Europe and in North America; and it suggests the possibilities of close correlation of widely scattered strata by means of conodonts. In North America these two paragenera seem to be confined to the Reeds Spring and Pierson of the Lower Osage group in Missouri.

A feature, not apparent in the chart but invitingly suggestive upon examination of species distribution in the European *cu*I stage, is the possibility, even the likelihood, that the Mississippian of Europe started very slightly later than in North America. In the oldest Mississippian conodont fauna in this continent in the "Siphonodella zone" as is described in later paragraphs, *Siphonodella sexplicata* is generally conspicuous along with *S. quadruplicata*, *S. duplicata*, and *S. lobata*. The first, together with *Pinacognathus*, seems to be indigenous to the initial Mississippian invasion only, whereas the other paraspecies of *Siphonodella*, with various paraspecies of *Elictognathus* and *Pseudopolygnathus*, range well up into the Kinderhook. There is some doubt about the identification of *S. sexplicata* in Europe. This idea of "later beginning of the Mississippian in Europe" is supported by the distribution of *Gnathodus* in the two continents. *Gnathodus* seems to be correctly identified in the earliest of the Gattendorfia stuffa (*cu*I) in central Europe but has not been identified in the North American Siphonodella zone. In this country its earliest record seems to be in the Cuivre formation, as is pointed out later.

PART II

DEVONIAN-MISSISSIPPIAN BOUNDARY FORMATIONS IN MISSOURI

The basal relations of the Mississippian system in Missouri involve a variety of sedimentary units with lithologies that range from limestone through unctuous clay, sandy clay shale, hard fissile dark gray or black shale, to sandstone. One of the greatest difficulties in achieving a satisfactory age and relationship assignment of these units lies in the similarity in appearance of the several sandstones involved and in the fact that in general they are barren of megafossils. The sandstones are widely distributed across the state in outcrops that are not readily traceable one to the other, and their identity has depended largely on the determination of their physical properties. The possibilities are evident that a widespread sand may vary markedly from place to place because of differences in source material, and that sands of different ages may be similar because they are derived from a common source.

Many of these isolated outcrops are productive of conodonts, and from the conodont evidence one must conclude that, in Missouri, sandstones ranging in age from upper Devonian to late Kinderhook have been accepted as time equivalents. Formation names have been applied accordingly and at present there seems to be little accord in age assignments of these several sandstones and their closely associated sedimentary types. Since I have been concentrating on the problems of basal Mississippian relations I have found that the identification of conodonts, coupled with the study of such megafossils and plant spores as are available,

offers a promising approach to the solution of some of the problems. It is my purpose, in the following pages to record some of the data accumulated over several years as a contribution toward the understanding of late Devonian and early Mississippian events in Missouri.

Historical Data

The occurrence of a sandstone or sandy shale at or near the base of the Mississippian in Missouri is recorded in geological literature as early as 1873 by Meek who wrote of "a thin greenish arenaceous band" at the base of the Chouteau in central Missouri (p. 175, Fig. 15). In the same year Broadhead (pp. 46–47) referred to a zone of similar position in Warren County as "The old Red Sandstone", the uppermost of three Devonian groups, and overlain by the Chouteau. He described it as not over seven feet thick and thinning to the westward and eastward.

Shumard (p. 306) noted a sandstone in Jefferson County beneath the Mississippian as follows:

> This system [the Devonian] is represented by a few feet of brown quartzose sandstone, usually occurring in a single bed. It may be seen on the Mississippi underlying the rocks described above (25 feet of reddish argillaceous limestone) at Sulphur Spring Landing and at the quarry near the mouth of Rattlesnake Creek. At these places the whole thickness does not exceed eight feet . . . We could not find fossils at any of the localities where the rock is exposed.

Shepard (p. 77) designated beds occurring beneath the "Hannibal shale" in Greene County, Missouri, the Phelps sandstone as follows:

> The Phelps sandstone is usually separated from the formation above it by a few inches of clay, or by a soft, impure, sandy clay, representing the unconformity between the Devonian and the Lower Carboniferous. The sandstone—best shown, perhaps, at the Phelps mines, is a peculiar rock—. It varies from a soft irregularly bedded, rather coarse grained sand-rock of a watery-green color, to an almost limpid quartzite-like stratum.

It is clear that Shepard considered the Phelps to be a Devonian formation and it is possible that he considered the overlying "soft, impure, sandy clay" to be an expression of the widespread sandy zone at the base of the Chouteau described by Meek, Broadhead and Shumard.

After these early notices this thin sandy clay zone beneath the Chouteau was recognized by many workers, but no name seems to have been suggested for it before 1918. In this year E. B. Branson (1918, p. 64) called this zone the "Sylamore sandstone", a name borrowed from the report of Penrose who in 1891 (pp. 113–114) described the Sylamore sandstone as well developed on Sylamore Creek in Stone County, Arkansas. Penrose presumably referred to any one of, or all, the sandstone beds intimately associated with the Chattanooga black shale at that place.

After Branson's publication, "Sylamore" became the accepted designation for the sub-Chouteau sand zone across Missouri. The distribution of the "Sylamore" in Missouri, as then conceived, was well summarized by Moore (pp. 111–112).

Ulrich (p. 110) described a sandstone in Jefferson County, east-central Missouri, as the Bushberg member of the Sulphur Springs formation and indicated that the sandstone was early Kinderhookian. The use of this name was not generally extended beyond the Jefferson County area until S. Weller (1928, p. 157) reported its presence in parts of Ste. Genevieve County.

Branson and Mehl (1933B, pp. 265–279) described a distinctive conodont fauna that occurs in the sandy clay zone at the base of the Chouteau throughout Missouri wherever the full thickness of the Chouteau or its equivalent occurs and designated it as the Bushberg conodont fauna. This fauna has been recognized subsequently by many conodont workers in outcrops and well cuttings all over North America and is conventionally referred to as the Bushberg fauna to the present time. It was in 1933 that Branson and Mehl (1933B, p. 266) "recognized their error" in designating this "Bushberg" zone as Sylamore up to that time.

In 1938 Branson (1938A, pp. 159–180) described a considerable megafauna which he designated as from the Bushberg sandstone. He collected this material from loose blocks along the roadside in Montgomery County, Missouri, "about seven miles west of Montgomery City on the old Montgomery City-Williamsburg road".

As of now there is no general agreement as to the proper use of the names Sylamore and Bushberg nor is there agreement as to the age and relationships of either. These and other names involved in the basal relations of the Mississippian in Missouri are reviewed in the following paragraphs.

INTERPRETATION OF TERMS AND RELATIONSHIPS

The Term Sylamore

The first published use of the term Sylamore sandstone was that by Penrose in 1891 (p. 114) to describe exposures in the region of Batesville, Arkansas, of a sandstone between the Silurian St. Clair limestone and the Boone chert as follows:

> Overlying this Silurian Terrane, is a bed of yellow, brown or gray sandstone often containing green or black shaley layers and sometimes merging into beds of the same material. It is frequently much stained by iron and sometimes contains small flat ferruginous concretions. This deposit is of very irregular distribution, sometimes being entirely absent and at other times revealing a thickness of thirty or forty feet. It is developed on a much larger scale in Stone County and the country to the west, than in the Batesville region, and is described under the name Sylamore sandstone, by Dr. Branner, in the report referred to and by Mr. T. C. Hopkins (report on marble and other limestones, Vol. 4 of the survey for 1890). It is supposed by Dr. Williams to be the equivalent of the "Black shale" of Tennessee and elsewhere in the Mississippi basin (see Dr. Branner's report).

Penrose stated that John C. Branner had named the Sylamore for outcrops in Stone County and although Branner's report was not published it must be assumed that Penrose considered Sylamore Creek in Stone County, Arkansas, to be the type locality.

Hopkins (p. 212) discusses the Sylamore as follows:

It (the St. Clair marble) is overlain by the Sylamore sandstone or the Eureka shale, one or both of which are generally present, but often in an unconspicuous bed only a few inches in thickness . . .

The Sylamore sandstone is generally an insignificant bed, being often but a few inches in thickness and readily disintegrating so that it is frequently overlooked even when present. It differs greatly in different parts of the area. In some places it is made up of rounded grains of hard crystalline quartz interspersed with black rounded, irregular pebbles; in other places it is a soft earthy rock of yellowish brown color; in still other places an arenaceous shale. The dark colored pebbles are a peculair feature of this rock, yet they are not always present. In a few places it forms a bed of considerable thickness; and in places south of Sylamore, it is fully forty feet thick.

The Eureka shale occurs at the same horizon as the Sylamore sandstone and is generally present in the absence of the sandstone, while in some places both sandstone and shale are present. However, in a general way, the sandstone occurs in the eastern part of the area and the shale in the western part.

This discussion and a series of thirteen sections across the state from east to west (Hopkins, 1893, facing p. 212) seem to emphasize the concept that the Sylamore sandstone is a facies of the Eureka black shale or the reverse. In section IV on Cagen Creek the "Sylamore sandstone-Eureka shale" zone consists of a sandstone below a considerable thickness of black shale; in section II on Sylamore Creek this zone consists of black shale, sandstone, and black shale, in ascending order; and in section VII on Dry Creek the zone consists of sandstone beneath a considerable thickness of black shale and argillaceous sandstone.

It is likely that both Penrose and Hopkins, in their designation of Sylamore sandstone, included strata of Mississippian age in some places, Devonian age in others, and in still others both Mississippian and Devonian ages. It is clear that both considered the Sylamore to be the same age as the Eureka black shale.

Subsequent studies seem to have done little to clarify the picture of the Sylamore, either as to position or age. Croneis (pp. 34–40) reports the situation as follows:

There is still some legitimate doubt as to the exact stratigraphic position of the Sylamore sandstone. At some places in northeastern Oklahoma the Chattanooga shale rests upon it . . . In the Fayetteville quadrangle the Chattanooga overlies the Sylamore with essentially the same relation, but at many of the outcrops of the Sylamore the Chattanooga is not found in the Eureka Springs-Harrison quadrangles . . . In the Batesville district a sandstone of sporadic occurrence, which is here tentatively regarded as the Sylamore, overlies a dark shale that Miser has called the Chattanooga but that Ulrich thinks is older than that formation.

The question, therefore, seems to be whether the Sylamore consists of two beds of sandstone and one bed of shale or of two beds of shale and one bed of sandstone. It appears to the writer, however, that the black shale found below the Sylamore sandstone east of the Harrison quadrangle is older than the typical Chattanooga and the Sylamore contains only a single bed of sandstone, which is probably the earliest Mississippian deposit in northern Arkansas.

And again (Croneis, pp. 41–42), in connection with the correlation of the Chattanooga:

If the Sylamore sandstone of Missouri and of Arkansas are of the same age, as there is reason to believe, then the Chattanooga shale, which overlies the Sylamore in northeastern Arkansas, must be Mississippian age.

Branson and Mehl (1933A, pp. 173–175, 180) indicate that the Sylamore and Bushberg are time equivalents (both basal Mississippian) and overlie the Grassy Creek and other black shales of approximately the same age. Later in the same year (1933B, p. 266) they recognized their error in using the term Sylamore to designate a Mississippian sandstone as follows:

> . . . We have pointed out the time gap between the Grassy Creek and the "Sylamore" on page 175 of this volume and now recognize our error in the application of the name Sylamore to the basal Kinderhook sandstone of central Missouri. The evidence is now clear that the Grassy Creek conodonts were in a residuum from the black shale and were reworked in the advancing Kinderhook sea that contributed Bushberg. This reworked upper few inches of the Noel must be considered Bushberg in age.

Contrary to expectations, an examination of the strata involved at or near the type locality of the Sylamore does not give an entirely satisfactory answer concerning either its age or relationships. The important details of such an examina-

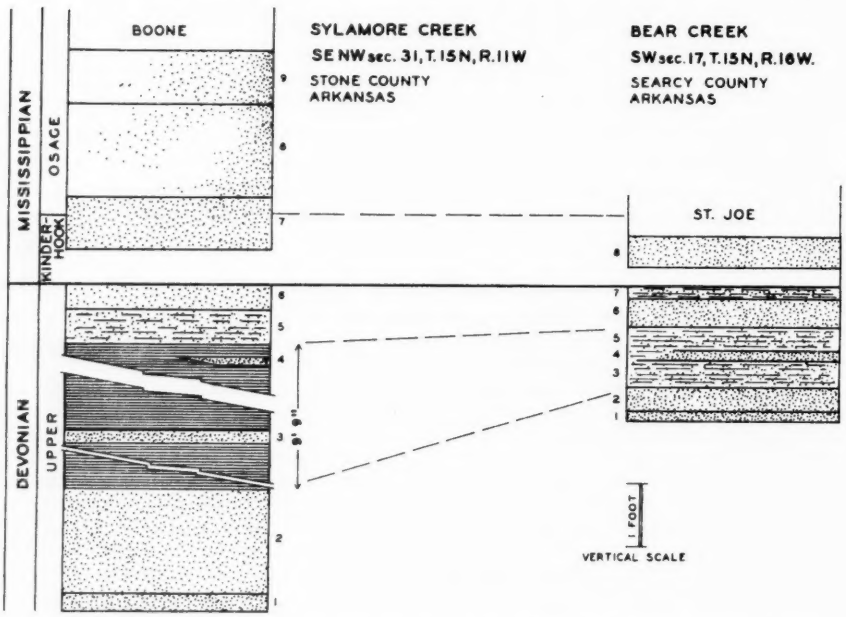

FIG. 2. Columnar section at the type locality of the Sylamore in Stone County, Arkansas, compared with a corresponding section in Searcy County, Arkansas. The figures beside the columns indicate conodont-bearing zones and do not necessarily indicate time equivalents.

tion are summarized in the accompanying illustration (Fig. 2) and serve primarily to point up a major reason for the varied use of the name Sylamore. All the sandstone of this section (indicated by numbers 1–9) provided an abundance of conodonts. Beds 1–5 contain typical late Devonian conodonts with no evidence of Mississippian forms. Beds 6–8 contain many typical Mississippian conodonts that bespeak a late Kinderhook or early Osage age. Inasmuch as there is no evidence of conodonts representing the earliest Kinderhookian, the presence of Devonian specimens in this upper succession is reasonably interpreted as admixtures from Devonian residues rather than transition from Devonian to Mississippian.

There is no way of determining to which of the several sands in this section either Branner or Penrose wished to apply the name Sylamore. If all the sands were to be included the incongruity is evident. The most conspicuous sands are beds 1 and 2 and beds 5 to 9. In the first case the sandstone is late Devonian in age. In the second case it includes strata of both Devonian and Mississippian age.

This section is not unique, but fairly typical of many that could be cited in northwestern Arkansas. One described by Maher and Lantz (p. 8) on Bear Creek in Searcy County, and later studied by Beveridge and Mehl differs from that on Sylamore Creek primarily in the absence of black fissile shale in the former. In this section there can be little doubt of the Devonian age of the several lower sandstone beds, all containing typical late Devonian conodonts and no evidence of Mississippian forms. The first appearance of Mississippian conodonts in this section is in a bed near the top where there is a considerable admixture of Devonian residue with middle or later Kinderhook forms.

Recommendations

At present there is no uniformity in the interpretation of the term Sylamore. One solution lies in the redefinition of the term, but it seems unlikely that there would be general acceptance of such a definition. I recommend that "Sylamore" be omitted from the list of stratigraphic names in Missouri.

The Bushberg Formation

Name

E. O. Ulrich (p. 110) described the Bushberg as the uppermost of the three members that constituted the Sulphur Springs formation.

Type Locality

The name indicates that the vicinity of Bushberg was meant to be the type locality, although it is reasonably certain that Ulrich was describing the outcrops at the Goetz Quarry near Glen Park. I now designate as type Bushberg the outcrops at the head of a ravine draining into the Mississippi River at Bushberg, a one time station on the St. Louis, Iron Mountain and Southern Railroad. This is in the NW NE NW sec. 8, T. 41 N., R. 6 W., Jefferson County, Missouri.

Distribution and Thickness

For the present it seems expedient to confine the name Bushberg to outcrops in Jefferson County and closely adjacent parts of Franklin and St. Louis counties, Missouri. This sandstone provides little useful data by means of which it may be correlated with isolated, widely separated exposures. There should be mentioned specifically the outcrops at Glen Park and at House Springs in Jefferson County, the exposures along the south bluff of theMissouri River in Franklin County to the south of St. Albins, and sandstone in the bluff overlooking the Missouri River at Castlewood in St. Louis County. There is no assurance that all of these sandstones are Bushberg in age. On the other hand, it is possible that outcrops farther to the north and west, designated later under another name, may be equivalent to the Bushberg.

The sandstone in Ste. Genevieve County, described by S. Weller (1928, p. 158) as slumped down over Glen Park and probably Bushberg, is a sandy bed in the midst of the Glen Park limestone. The early Mississippian age of the conodont fauna described as from the "Bushberg" by Branson and Mehl (1933B) is not questioned, but it should be pointed out that its identification as a Bushberg fauna is not supported by the evidence at hand. The same applies to Peck's reference of charaphytes from central Missouri to the Sylamore (Bushberg). Morey's paper on ostracods from the "basal" Mississippian (Bushberg) sandstone describes specimens that came from the same locality as Peck's Mississippian charaphytes, and the identification of these strata as Bushberg is questioned. The fauna from the "Bushberg" described by E. B. Branson (1938A, pp. 159–183) should not be considered valid evidence of the age of the Bushberg. The sandstone from which the fauna came is isolated and far removed from the Bushberg as herein restricted and its relationships are not clear.

The thickness of the Bushberg varies from about 5 feet near St. Albins to somewhat more than 12 feet at House Springs. The average is probably 10 feet. At Bushberg there is currently exposed about 12 feet of the sandstone. The distribution is discussed in an earlier paragraph.

Lithology

In most of the outcrops that can be identified as Bushberg the lower 4–6 feet are massively cross bedded and the upper part is massive, even bedded. On fresh exposures the sandstone is light gray to pale yellow. The weathered surfaces are various shades of reddish brown with the darker shades predominating. The Bushberg consists of medium to fine grained, well rounded quartz, with a small proportion of very fine grains. In some exposures calcareous oolites are evident; and in a few localities there is a recognizable admixture of clay. In only a few places is the calcareous cement conspicuous, although in some outcrops there are lenses that are thoroughly cemented. For the most part the Bushberg is not friable on fresh exposures.

Paleontology

I have found no evidence of megafossils in the Bushberg, as limited above, but there are few exposures where it is possible to investigate fully their possible oc-

currence. At most places conodont fragments may be expected but these are broken and suggestive of detrital material. I have identified many Ordovician and Devonian forms, but none suggestive of Mississippian age. The fairly common occurrence of sporangites,* presumably of the genus *Tasmanites*, is significant. These "mega-spores" are fairly abundant in the −60 screen size in the exposures at Castlewood and some other localities.

Stratigraphic Relations

The Bushberg is unconformable on Maquoketa, Kimmswick or the "Fernvale", the Grassy Creek, and the Glen Park. There are marked variations in the thickness of the Glen Park over short distances, as indicated elsewhere in this report; and in some places the Bushberg fills the sharply outlined irregularities. An unconformity above the Bushberg is best marked by the generally well developed layer of small to large phosphatic masses in the immediately overlying sand, the Bachelor, described later.

Age and Correlation

The age of the Bushberg has been accepted generally as early Mississippian. This probably arises through the fact that it overlies the Glen Park which, subsequent to S. Weller's (1906) publication on its fauna, has been accepted as Mississippian in age. Furthermore, the reports of Mississippian fossils in the "Bushberg" by Branson and Mehl, and others, seem to have bolstered the belief that the Bushberg is Mississippian in age without adequate evidence that the fossil-bearing strata are correctly identified as Bushberg.

Elsewhere the possibility is pointed out that the Bushberg is a close correlative of the Devonian Massie Creek (herein described). The occurrence of species of *Tasmanites* in the Bushberg bespeaks Devonian age. I have been unable to verify the occurrence of this genus in sediments of undisputed Mississippian age. More important, perhaps, is the occurrence of the typical basal Mississippian "*Siphonodella*" conodont fauna immediately overlying the Bushberg in one locality. Furthermore, in every place where the Bushberg can be identified with some degree of certainty, a marked unconformity between it and the overlying Mississippian is indicated by a bed of intervening phosphatic nodules. I believe it advisable to place the Bushberg, tentatively, in the late Devonian.

The Term Phelps

Shepard, in 1898, gave the name Phelps to a sandstone occurring in Greene County, Missouri, overlying the "King" or the "Sac" limestone and underlying the "Louisiana" limestone or "Hannibal" shale. He described it as follows:

> . . . It varies from a soft, irregularly bedded rather coarse grained sand-rock of watery green color, to an almost limpid quartzite-like stratum . . . almost invariably the sandstone forms a matrix for more or less angular, water worn, flint pebbles, which vary from the size of a mustard seed up to two inches in diameter . . . An important feature of this formation

* This term is used in the sense suggested by Schopf, Wilson, and Bentall (1944, p. 11), "to record the presence of more or less disc-shaped, resinous appearing bodies . . . many. . . of which are properly referable to *Tasmanites* . . . *Sporangites* is considered a *nomen ambiguum* by these authors".

is the presence of fish teeth, which occur abundantly and which are widely distributed, all being water-worn . . .

The best locations for the study of this sandstone are as follows: In township 28 N., R. 1 W., sec. 1, NW ¼ or NW 1/r at the Phelps mines, . . . and the old mine dumps around the shafts form a good collecting ground for the fish teeth and variations of the sandstone. . . . As these mines were the point of first discovery of the fish teeth . . . the provincial name of Phelps sandstone has been given to this horizon.

The Phelps sandstone as defined above has not proven to be a useful unit in stratigraphic studies except, perhaps, as a subsurface "catch all". None of the pits of the several mining operations mentioned by Shepard has been open for many years, and an inspection of many dumps has not provided materials that give a satisfactory picture of the unit described by him. Some of the dump samples from the old Phelps mine illustrate the worn fish teeth supposedly typical of the Phelps, but the bulk of the sandstone samples depart markedly from the physical properties of these. If it could be reasonably assumed that all the sandstone Shepard included in the Phelps is of the same age as the "fish teeth bearing" samples there would be little question of its age. Several such samples have yielded a conodont assemblage of unquestioned early Kinderhook age.

The surface exposures identified by Shepard as Phelps on Asher Creek in Greene County (sec. 9, T. 30 N., R. 23 W.) have been flooded in recent years; but exposures of strata in Christian County occupying the same stratigraphic position (below the Compton and above the Cotter) suggest several possibilities for interpretation of the bed or beds involved in the "Phelps". In sec. 29, T. 27 N., R. 22 W., at the Frazier bridge, the Cotter is succeeded by 7–10 inches of soft brown or buff sandstone and hard white sandstone similar to samples from several of the mine dumps mentioned by Shepard. Above this sandstone is a variable thickness (5 to 11 feet) of black fissile Devonian shale. Between this and the Compton are 2 to 3 feet of pale greenish silty clay, water green sandstone containing large pebbles, and a thin zone of green sandy clay at the top. The sandy succession above the black shale contains an abundance of early Mississippian conodonts. In another section, about ⅜ of a mile downstream, exposed by trenching, no black shale is exposed in the interval between the Cotter and the Compton. Here a light gray sandstone (4 to 8 inches thick) which yields typical late Devonian conodonts is followed by 16 to 20 inches of yellowish-green clay shale containing typical early Mississippian conodonts with an admixture of worn Devonian forms. Between this shale and the Compton is an irregular bed of water-green "glint" sandstone (4 to 7 inches thick) containing early Mississippian conodonts.

These two sections illustrate the patchy distribution of the Devonian black shale and point up the possibility that any section including the post-Ordovician to early Mississippian in this general area may consist of one sandstone, either Devonian or Mississippian, or of two sandstones, one of each age.

Recommendations

In the light of uncertainty of the stratigraphic connotation of the Phelps as conceived by Shepard I suggest that this term be dropped from the list of names in the Missouri columnar section.

The Massie Creek Sandstone (New)

Name

The name Massie Creek is proposed for a highly calcareous fossiliferous sandstone that is well developed and exposed along Massie Creek and some of its tributaries in Warren County, Missouri.

Type Locality

An outcrop of limited extent in the NE cor., SW SE NW sec. 24, T. 47 N., R. 4 W., in Warren County, Missouri, two miles south of the center of Jonesboro (which is in Montgomery County), shows well the relations and characteristics of the sandstone. There is promise of permanency of the outcrop and accessibility to it. The above, therefore, is designated as the type locality.

Distribution and Thickness

The Massie Creek sandstone probably does not exceed 10 to 12 feet in thickness and the average may be as little as 5 feet. At the type locality it is about 7 feet thick.

The westernmost outcrop, identified with some assurance, is in Boone County near Brown's Station. The outcrops fartherest east are near New Melle in St. Charles County. There are excellent exposures near Holts Summit in Callaway County (sec. 13, T. 45 N., R. 11 W.) and some isolated exposures a few miles north of Big Springs near State Highway 19 in Montgomery County. Some good exposures occur south of Warrenton on Charette Creek. This is the general area in which Broadhead (p. 46) found and described the "Old Red Sandstone", presumably the Massie Creek. In Boone, Callaway and parts of Montgomery Counties the sandstone is discontinuous and for the most part is valley-fill in sharply outlined channels. One of the best examples of this is at the Holts Summit locality cited above.

Lithology

The Massie Creek varies from light gray, or almost white, to medium gray and light yellowish brown on fresh exposures. Weathered surfaces tend toward medium or even dark reddish brown. In most outcrops calcareous oolites are conspicuous but the grains are preponderantly of medium size, well rounded quartz. Small polished phosphatic pellets are conspicuous in some outcrops. Marked cross-bedding characterizes the sandstone and is most conspicuous in the lower half of the formation. For the most part the sandstone is thoroughly cemented with calcareous cement and is relatively hard. In only a few places could the sandstone be described as friable.

Paleontology

The paleontology of the Massie Creek has not been thoroughly studied, but the limited number of fossils identified to date indicate what may be expected. Among the considerable number of samples processed for microfossils most have been barren except for worn fragments of Devonian conodonts. However, in the

SW SW sec. 3, T. 47 N., R 5 W., in Warren County, the lower part of the sandstone produced a few late Devonian conodonts that are interpreted as indigenous. In several places the sandstone has produced megafossils, primarily brachiopods of some variety. Most distinctive among these are Atrypids, Schizophorids, and Syringotherids. George Fraunfelter has identified the following:

Atrypa rotunda Stainbrook
Spirifer annae Swallow
Syringothyris m. spp.
Schizophoria Striatula (Schlotheim)
Delthyris missouriensis (Branson)
Productus spp.
Dalmanella m. sp.
Stropheodonta demissa (Conrad)?
Syringothyris sp., of *S. occidentalis* (Swallow)

These fossils are moderately abundant in the lower half of the formation at the type locality. They are also fairly abundant in the lower part in the SE SE sec. 33, T. 46 N., R. 2W., and in SE SE sec. 14, T. 47 N., R. 4 W.

Stratigraphic Relations

The Massie Creek formation is unconformable below the Mississippian "Siphonodella beds", described in later paragraphs. It is unconformable on beds ranging from Plattin to Holts Summit (described later), including Kimmswick, Callaway, Synder Creek, and Glen Park. The unconformity below the Massie Creek is evident not only in the variety of subjacent formations but in the marked irregularity of its lower surface. This is particularly noticeable in its western extent where it constitutes valley-fill in sharply outlined channels.

Age and Correlation

Although some of the conodonts suggest a late Devonian age for the Massie Creek this interpretation might be questioned. However, the fair abundance of such brachiopods as *Atrypa rotunda* Stainbrook, *Schizophoria striatula* and *Stropheodonta demissa* Conrad, leave little doubt of the Devonian age. It is interesting to note in this connection that the fauna includes at least one species of *Productus*.

The stratigraphic relations of the Massie Creek and the Bushberg are similar, and it is possible that subsequent evidence may show that they are time equivalents. As pointed out elsewhere no records of diagnostic fossils in the Bushberg to date are recognized in this report as valid.

Recommendations

I recommend, as an aid to minimizing confusion, that the two names, Bushberg and Massie Creek, be recognized unless and until the two are proven to be synonymous. In such an event it is doubtful whether the latter name should be

dropped inasmuch as these two units have different geographic distribution and are markedly different in their physical properties.

The Term Sulphur Springs

The Sulphur Springs formation was described by Ulrich in 1904 (p. 110) as follows:

> In the area about Glen Park and Sulphur Springs I have further distinguished, at the base of the Kinderhook and perhaps top of the Devonian, the Sulphur Springs formation. This formation is divided into three members, a thin sandstone (about 10 feet) at the top to which the name Bushberg sandstone may be applied; beneath this a 1 to 5-foot bed of oolitic limestone, probably early Kinderhook in age, which may be called the Glen Park (oolitic) limestone; and, finally, at the base a shale, 0–15 feet thick, either earliest Kinderhook or late Devonian in age, for which no subordinate designation is proposed.

S. Weller (1928, p. 157–158), describing occurrences of Sulphur Springs in Ste. Genevieve County, Missouri, proposed that a fourth member be included in the Sulphur Springs formation as follows:

> In Ste. Genevieve County the basal shale member of the formation has not been certainly recognized, but the Glen Park limestone and the Bushberg sandstone members are well exhibited. In addition to these there is in one locality in the county, in SW ¼ SE ¼ sec. 29, T. 37 N., R. 9 E., another shale member lying above the Bushberg sandstone which may be included in the Sulphur Springs formation.

And again:

> The uppermost, black shale member of the Sulphur Springs formation has been observed only in one locality, already mentioned . . . The greater portion of the rock is a black, carbonaceous shale, similar to the exposures of the Chattanooga shale in southern Illinois, Kentucky and Tennessee . . . Imbedded in the shale there are a few examples of *Sporangites* similar to those in the Chattanooga shale . . .

It must be assumed that Ulrich meant the vicinity of Sulphur Springs to be in the type locality. This is a station on the Missouri Pacific Railroad along the Mississippi River bluff in Jefferson County, Missouri. The choice of name was unfortunate because in the place of the best exposures, 0.3 miles north of the station, there is no evidence of strata that may be assigned to the Glen Park, and the sandstone "at the base of the Kinderhook" does not fit Ulrich's description of the Bushberg. It is likely that it was the shale of this locality that led to Ulrich's stated maximum thickness of 15 feet for the bottom shale member of the Sulphur Springs. The shale here, about 15 feet thick, includes a black fissile shale at the top containing sporangites and conodonts of Upper Devonian age. The lower several feet of the shale section is Maquoketa (Ordovician).

Recommendations

Neither the Bushberg nor the Glen Park are coextensive with the widespread upper Devonian black shales of Missouri; and the Bushberg is unconformable

on the Glen Park, as will be shown in another place. It appears incongruous to group Devonian black shale with the Glen Park and Bushberg sandstone as a formation or as members of a group. I suggest that the term Sulphur Springs can be dropped as a group or formation name from the Missouri stratigraphic column. Elsewhere it will be shown that the fourth member of the "Sulphur Springs", proposed by S. Weller (1928. p. 158), was mistakenly thought to be above the Bushberg. The sandstone to which Weller referred rests on the Maquoketa and is Devonian in age. Glen Park is not identified with certainty above the black shale that overlies this sandstone; and the Bushberg is missing in this section.

The Glen Park Formation

Name

Ulrich (p. 110) proposed the name Glen Park for an oolitic limestone, the middle member of three constituting the Sulphur Springs formation as follows:

> In the area about Glen Park and Sulphur Springs I have further distinguished, at the base of the Kinderhook and perhaps top of the Devonian, the Sulphur Springs formation. This formation is divided into three members, a thin sandstone (about 10 feet) at the top to which the name Bushberg sandstone may be applied; beneath this a 1 to 5-foot bed of oolitic limestone, probably early Kinderhook in age, which may be called the Glen Park (oolitic) limestone; and finally, at the base a shale, 0–15 feet thick, either earliest Kinderhook or late Devonian in age, for which no subordinate designation is proposed.

Type Locality

Although no type locality was designated by Ulrich it is evident that he had the vicinity of Glen Park in mind. Glen Park is a small community in Jefferson County, Missouri, on the Mississippi River. The best and the most readily accessible outcrops of the Glen Park limestone are a short distance south of this community in the SE cor. SE NE sec. 5, T. 41 N., R. 6 E., in the old quarry face along the river bluff above the Missouri Pacific Railroad. This should be considered the type locality. Although the Glen Park is thin at this locality it is very fossiliferous and the distinctive physical properties are much the same as are found in places where the formation is thick and the lithology more varied.

Distribution and Thickness

The Glen Park outcrops form a northwest-southeast trending band roughly paralleling the Mississippi River through Ste. Genevieve, Jefferson, Franklin, St. Louis, St. Charles and Warren counties, Missouri. In Ste. Genevieve County outcrops that are usually good, but change from season to season, may be found in the northern part in Snell Hollow, SE NW SE sec. 24, T. 39 N., R. 7 E. The likely occurrences of Bushberg at this place, mentioned by S. Weller (1928, p. 157), are exceptionally sandy lenses in the midst of the Glen Park limestone. In Coal Hollow, SE NW SE sec. 29, T. 37 N., R. 9 E., the sandstone, thought by Weller to be Bushberg, lies below fissile black shale, the lowest of the three members of Ulrich's Sulphur Springs. Above this black shale and below the

Fern Glen there is a poorly exposed section, about 8 feet thick. It is made up, in part, of reddish gray, somewhat fissile shale and gray sandy shale, all bearing Devonian conodonts and an abundance of sporangites, probably species of *Tasmanites*. It is possible that this poorly exposed section should be referred to the Glen Park rather than to the Chattanooga.

In Jefferson County the chief outcrops center around Glen Park, as indicated above, and near House Springs in sec. 3, T. 32 N., R. 4 E. In Franklin County the outcrops of Glen Park seem to be confined to the Missouri River bluffs along the Chicago, Rock Island and Pacific Railroad, about a mile northeast of St. Albins. In St. Louis County at Castlewood (SW SW SE sec. 15, T. 44 N., R. 4 E.) 8 to 14 inches of grayish green sandy shale and thin flaggy calcareous sandstone that contains small polished phosphatic pebbles probably represents the Glen Park. It is overlain by the Bushberg sandstone. In St. Charles County exposures recognized as the Glen Park are confined to the west central part in the vicinity of New Melle. Excellent exposures are found in small gullies tributary to Dardenne Creek in sec. 24, T. 46 N., R. 1 E. A succession of siltstone and calcareous sandstone totaling about 5 feet, tentatively referred to the Glen Park, occurs in the SW NW SW sec. 32, T. 46 N., R. 1 E. and SW sec. 20, T. 46 N., R. 1 E.

The thickness of the Glen Park varies from a few inches to more than 20 feet. At the type locality, as given above, probably no more than 30 inches should be assigned to the formation, and it is entirely lacking less than ¼ mile to the west. One of the greatest thicknesses was measured in a section on Dardenne Creek SW NW sec. 24, T. 41 N., R. 1 E., where the formation totals approximately 30 feet. The greatest thickness observed in Warren County is no more than five feet.

Lithology

The Glen Park is a lithologic unit in that it contains, in all its facies, well rounded, poorly-sorted quartz sand, and highly polished phosphatic pellets that vary in color from black to orange or pearl gray. In all known outcrops medium gray or pale yellowish limestone is included in the succession. In most places the limestone facies is cross-bedded coquina consisting of broken and worn shell fragments and a lesser amount of poorly preserved shells. In some places the limestone is evenly bedded and hard. In Ste. Genevieve County the succession consists of 2 to 4 feet of limestone, 12 to 18 inches of poorly cemented highly calcareous sand or sandstone, and 18 to 36 inches of shell-bearing limestone similar to the lower unit. On Dardenne Creek in St. Charles County calcareous siltstone and sandstone make up the greater thickness with cross-bedded limestone confined to the lower part.

Stratigraphic Relations

The Glen Park is separated from underlying strata by an unconformity involving Kimmswick, Maquoketa, Chattanooga, and probably the upper Plattin in some localities. At the locality in Warren County, cited above, the upper contact is well exposed and shows the Massie Creek sand filling sharp irregulari-

ties in the upper surface of the lower Glen Park limestone. Where the Bushberg overlies the Glen Park the unconformity is not evident except in the sharp change in lithology.

Paleontology

To the megafauna described by S. Weller (1906) can be added conodonts and spores. At nearly every exposure conodonts have been found in some abundance. Most of these are broken and abraded, but some specimens have been collected that are interpreted as indigenous. Sporangites in considerable abundance have been found in several exposures by acidizing the limestone facies. These spores have not been systematically studied but seem to represent one or more species of *Tasmanites*.

Age and Correlation

In 1906 S. Weller (pp. 462–464), with some hesitancy, concluded that the Glen Park is Mississippian in age and probably the approximate time equivalent of the Hamburg oolite of Calhoun County, Illinois. Since that time this age and relationship has been generally accepted. The conodonts that have been found in the Glen Park show trituration. Most of them are recognizable as Devonian forms and may be interpreted as admixtures. However, some well preserved specimens of upper Devonian age have been collected that strongly suggest indigeneity to the beds. It is important to note that none can be identified as of Mississippian form.

The best evidence of Devonian age of the Glen Park is that in places it is overlain by the Massie Creek sandstone in which fairly abundant megafauna occurs. This fauna, as indicated elsewhere, argues strongly for the Devonian age of the latter.

I have found no evidence that either confirms or is contrary to Weller's correlation of the Glen Park with the Hamburg.

Recommendations

Its unconformable relation above and below, its moderately wide distribution, its distinctive fauna, and the varied lithology within its boundaries justify recognition of the Glen Park as a formation, which I recommend.

The Holts Summit Formation (New)

Name

The name Holts Summit is proposed for a sandstone-shale succession that crops out near the village of Holt's Summit in the southwestern part of Callaway County, Missouri.

Type Locality

The NE SE SE sec. 11, T.45N., R. 11 W., on a major branch of Clifton Creek about 2.3 miles north and 0.5 mile west of Holt's Summit, is designated as the type locality for the formation. The exposures here are typical and show

the relationships well. This locality is readily accessible and promises to offer good exposures for many years to come. Excellent exposures are also found in the extreme southeastern corner of the above designated section, and in the SE SW SE sec. 14, T.45N., R. 11 W., all in Callaway County.

Distribution and Thickness

The known distribution of major outcrops of the Holts Summit is confined to an area of about 30 square miles in the southwestern part of Callaway County, Missouri. It does not seem likely that many outcrops will be found beyond these limits although there are two noteworthy exceptions. One of these is about 75 miles to the west and south, in Benton County. Here, in a roadside ditch along County Highway T, SE NE NE SW sec. 13, T. 41 N., R. 23 W., the fauna of the Holts Summit has been identified in a shaly sandstone succession approximately four feet thick. The other widely isolated outcrop is in Boone County on the Missouri River near Providence, about 18–20 miles to the west and north of the type locality. At this place the fauna of the Holts Summit has been identified in the channel fill that Branson and Mehl (1933A, p. 173, fig. 5, p. 178, loc. 10) identified as Grassy Creek in 1933.

The average thickness is probably about four feet with a maximum not more than 8 to 10 feet. Variations in thickness are due primarily to differences in the thickness of the lower bed or beds which range from 5 or 6 inches up to 18 inches or more in very short distances. It is certain that there was erosion to various depths in some places before the deposition of the overlying Massie Creek sediments.

Lithology

The Holts Summit consists of alternating beds of sandstone and noticeably arenaceous shale. In most places the lowest sandstone, the base of the formation, is the most conspicuous, ranging from 6 to 18 inches thick. It is very light gray or white in fresh exposures but weathers to a slightly brown, case hardened surface. It consists of moderately uniform medium size quartz grains that show marked crystal regrowth. The sandstone is well cemented, massively cross bedded, and on its under surface records mud cracks and worm borings. The first sandstone is normally followed by a thickness of 5 to 25 inches of arenaceous clay shale or poorly cemented highly argillaceous sand, the quartz grains of which are similar to those of the first sandstone. This second unit is color banded, blue-green to brown or light gray. In some exposures this unit contains sandstone lenses or one or more continuous thin sandstone beds. In most places a third sandstone bed is recognized which is very similar to the lowest unit except that the upper sandstone is uniform in thickness, ranging from 5 to 8 inches, and has a somewhat irregular upper surface.

Stratigraphic Relations

Throughout its known occurrence the Holts Summit rests unconformably on the Snyder Creek or Callaway. The Snyder Creek involved in most places consists predominately of gray dense limestone and it is possible that in some

places suppossed Snyder Creek should be designated as Callaway. There is an unconformity at the top of the Holts Summit involving the Massie Creek or the Bachelor. In most places there is parallelism between the Massie Creek and the Holts Summit, but the unconformity is well marked by the "biscuit bed" of the Massie Creek, a sandstone unit with closely crowded "flattened balls" of phosphatic material. These nodules, commonly circular, average perhaps 5 inches in diameter. In places the Massie Creek fills sharply outlined channels in the Holts Summit up to 6 or 8 feet deep. The upper relations are not everywhere evident, but it is clear that in some places the Bachelor formation rests directly on the Holts Summit.

Paleontology

Except for sparsely scattered lingulate brachiopods in the upper part of the Holts Summit in a few exposures, no fossils other than conodonts have been noted. In most localities conodonts are abundant in the lower part of the first sandstone and occur in moderate abundance in the higher units. In the lowest bed of sandstone the conodonts are distributed along the planes of the cross-bedding. In some cases they are so abundant as to be apparent as dark bands alternating with the clear quartz-grain units.

Age and Correlation

The Holts Summit is undisputably Devonian in age. The form-genus *Palmatolepis*, no place in the world recorded in sediments of undisputed Mississippian age, makes up essentially 50 percent of the total population. In addition such typical Devonian genera as *Ancyrodella*, *Ancyrognathus*, *Nothognathella* and *Icriodus* are well represented. Conodonts are more varied and abundant in the Holts Summit than in any other stratigraphic unit with which I have had experience; and it is hoped that when our studies are completed this fauna will become a standard for comparison and correlation. At present, however, it is difficult to assign it to a precise age. In the first place, comparison with the Grassy Creek and the Noel shale of Missouri is not satisfactory. I now recognize that most of the specimens described by Branson and Mehl in their "conodont fauna of the Grassy Creek" came from the overlying Saverton. A few of the specimens came from the Holts Summit. The Noel has actually contributed little except as admixture in the basal strata of the overlying Mississippian. There are unique forms in the Holts Summit that are not suggestive of close relationship with the Sweetland Creek, Olentangy, Darby, or the Saverton. Comparison with upper Devonian conodont forms of central Europe are equally unsatisfactory although there is some similarity between the fauna of the Holts Summit and that of the European upper Cheiloceras and lower Platyclymenia zones. See Fig. 1. The position of the Holts Summit (unconformable on the Synder Creek) and the absence of typical middle Devonian forms bespeak an upper Devonian age for the Holts Summit.

The Grassy Creek Shale

Name

The name Grassy Creek was proposed in 1898 by Keyes for "black and green shales in northeastern Missouri underlying the Louisiana limestone near Louisiana in Pike County, carrying characteristic Devonian fish".

He referred to a thickness of thirty feet for these shales "ten miles west of Grassy Creek" (presumably on Grassy Creek about six miles west of Louisiana); and in 1933 Branson and Mehl (1933A, pp. 171, 172) pointed out that the lower part of the shale succession here included a considerable thickness of Maquoketa. Previously Krey (p. 23) had called attention to the Maquoketa in sec. 19, T. 54 N., R. 2 W., on the south banks of Grassy Creek below hard fissile black shale which he assumed to be of Ordovician age because he thought it to be beneath the Noix. In 1913 Keyes (pp. 160, 162) restricted the Grassy Creek to the black part of the "black and green" shales by designating the upper "blue" shales as the Saverton. In 1935 J. Weller (pp. 191, 192) proposed dropping the name Grassy Creek as follows:

> The confusion that has resulted from the misinterpretation of the Grassy Creek section seems to necessitate a redefinition of formations. The simplest solution is to relinquish the name Grassy Creek for the basal black Kinderhook shale. If it is desirable the name might be redefined and applied to the dark shale member of the upper part of the Maquoketa. At the present time it does not seem advisable to distinguish between the black shale from the overlying greenish or blue beds and it is therefore proposed to expand the Saverton formation to include the basal Kinderhook black shale exposed in the vicinity of Louisiana which have been known formerly by the name Grassy Creek.

The "confusion" Weller reports in a preceding paragraph is here quoted:

> Branson and Mehl state that they have collected "Grassy Creek" conodonts from the shales in sec. 19 on Grassy Creek but in none of their systematic descriptions is any reference made to this locality. We may conclude, therefore, that probably the conodont fauna obtained at this place was very scanty or poorly preserved and perhaps was not sufficiently diagnostic for an accurate age determination. Scepticism regarding their statement is occasioned by the occurrence of fragmentary graptolites in the dark shale member.

Weller assumes that the "green and black" shale beneath the Louisiana limestone at Louisiana, designated as Grassy Creek by Keyes, is Mississippian. He states that the shale identified as Grassy Creek by Branson and Mehl (about six miles west of Louisiana on Grassy Creek) is not the same age as that of the shale below the Louisiana at Louisiana because it is not Mississippian. This conclusion is based on the assumption that Branson and Mehl did not have sufficient conodont evidence to establish its age and on the fact that Weller had found in it fragments of graptolites (not generically identified) which are not found in the Mississippian. Weller does not mention the fact that Branson and Mehl designated the beds in question as late Devonian nor does he mention the possibility that, in the light of a fairly abundant record of Devonian graptolites

in North America, there was some possibility of a Devonian age for the shales. If Weller found the graptolites in the part of the section designated "Grassy Creek" by Branson and Mehl one may expect them confidently in the shale at Louisiana, the shale that Weller designates as basal Mississippian.

Type Locality

Keyes gave the name Grassy Creek to a thickness of "about 6 feet of black and green shales" immediately beneath the well defined Louisiana limestone, in the vicinity of the town of Louisiana. Although he did not mention a precise locality it is evident that he intended the type locality to be in this area of the thin Grassy Creek and not "ten miles west of Grassy Creek", where these shales attain a thickness of 30 feet. Branson and Mehl (1933A, p. 176) have described three specific localities at Louisiana, two on Town Branch within the present city limits and one "about 600 feet up the river from the Champ Clark bridge". The first two outcrops change from season to season, but the third gives promise of little change over a period of many years. This then, the Mississippi River bluff in Pike County, Missouri, some distance above the Champ Clark bridge (approximately SW NW NE sec. 18, T. 54 N., R 1 W.) is designated as the type locality of the Grassy Creek as emended by Keyes in 1913. The section is figured by Branson and Mehl (1933A, p. 173, fig. B) and it is compared with the section six miles to the west on Grassy Creek.

Branson and Mehl, in their paper, "Conodonts from the Grassy Creek Shale of Missouri" (1933A,) did not distinguish between their supposed distribution of the "Grassy Creek conodont fauna" and the distribution of the Grassy Creek shale. As a result they seem to suggest the substitution of the name Grassy Creek for such regional designations of strata as Noel, Chattanooga, etc. This, I believe, was ill-advised for stratigraphy is served best by retaining regional designations of strata even when there is complete agreement on correlation from place to place.

Outcrops of Grassy Creek, as here recognized, are confined to northeastern Missouri. As presently known this includes exposures northeast of the Lincoln Arch in Pike, Ralls, and Marion Counties and possibly patches in Lincoln County.

Thickness and Distribution

The average thickness of the Grassy Creek at outcrop is probably less than five feet with maximum thickness of about 20–25 feet on Grassy Creek about 6 miles west of Louisiana. At and near the type locality it varies from three to five feet. At Clinton Spring on the Mississippi bluff near the south edge of Louisiana the Grassy Creek is about 4 feet thick, and farther to the southeast at the Pinnacle (SW SW sec. 9, T. 53 N., R. 1 E.) it is between 3 and 4 feet. In Ralls County the chief Grassy Creek outcrops are in the vicinity of New London where the maximum thickness is probably not more than 15 feet. In the SW NE sec. 33, T. 56 N., R. 6 W., it is about 5.5 feet. The average for the Ralls County outcrops is probably less than 10 feet.

Subsurface data record late Devonian strata with lithology like that of the Grassy Creek in northern and northwestern Missouri. This should be designated as Grassy Creek with question.

Lithology

The Grassy Creek is a very dark gray to dark brownish gray or even black, hard fissile shale. In most localities small pyrite crystals, sparsely dispersed throughout the thickness, may be expected. At the type locality the basal part is markedly pyritiferous. Sandy zones may be expected but they are not characteristic. In most places the shale weathers to small thin plates. A fossiliferous sandstone found at the base of the Grassy Creek in many places is described elsewhere in this report as the Turpin sandstone member.

Stratigraphic Relations

The Grassy Creek shale, unconformably below, rests on Maquoketa, Cyrene, Bowling Green and Callaway in various places. Where the Turpin sandstone is recognizable no unconformity is noted between it and the Grassy Creek. There is a sharp color and lithologic break between the Grassy Creek and the overlying Saverton shale; but there is some question as to whether the relationship is one of unconformity.

Paleontology

Aside from fish bones reported by Keyes (1897, p. 63), Rowley (pp. 30, 31) E. B. Branson (1914) and others, the reported megafossils of the Grassy Creek are confined almost entirely to linguloid brachiopods. There is some question as to whether the fish remains reported came from the Grassy Creek or from the Saverton. J. Weller (1935) reports graptolite fragments in the part of the section on Grassy Creek identified by Branson and Mehl as Grassy Creek shale. Branson and Mehl reported a conodont fauna from the Grassy Creek consisting of more than 100 species distributed among some 20 genera (1933A.) Unfortunately, this is not a true picture of the Grassy Creek conodont fauna. At that time we stated that in our opinion the Saverton was not a formation but the weathered upper part of the Grassy Creek. Conodonts in the Grassy Creek shale as now defined are much less abundant than in the Saverton. In checking over locality sources of the conodonts we figured as Grassy Creek, I find that most of the specimens came from the Saverton and that some of them came from sandstones that are elsewhere herein designated as Holts Summit. However, I am confident that the list given by Branson and Mehl does not depart greatly in its major aspects from that of the Grassy Creek fauna. As a matter of fact, the essentials of the fauna listed can be duplicated in the Grassy Creek at its type locality, particularly in its basal pyritiferous zone.

Age and Correlation

As pointed out above, there is no adequate conodont record on which sound appraisals of Grassy Creek correlation can be based. On the other hand, the

formation is restricted by the Saverton fauna above and the Turpin fauna below, both upper Devonian.

The Turpin Sandstone (New)

Name

The name Turpin comes from a small crossroads community in the SW cor. sec. 5, T. 52 N., R. 1 E., Pike County, Missouri, and is applied to a sandstone at the base of the Grassy Creek shale.

Type Locality

The type locality of the Turpin sandstone is at a spring near the roadside in NW SW NE sec. 3, T. 52 N., R. 1 E. (approximate), almost 2 miles east, 0.5 mile north of Turpin. This outcrop is selected because it shows well the nature of the sandstone and about its average thickness, although the upper relations are not clearly exposed. In addition, from this particular outcrop has been collected a representative conodont fauna.

Lithology

Although the physical properties of the Turpin vary considerably from place to place, the sandstone is in general a pale buff and becomes various shades of brown and reddish brown upon weathering. The grains, largely quartz, are not well sorted, are of medium size and in most places not well-rounded or frosted, but angular with marked evidence of crystal regrowth. The bedding ranges from a single massive unit to two or more even-bedded or markedly cross-bedded units. In other places the typical sandstone grades laterally into a sandy, unctuous blue-gray clay shale. In some localities it is represented by a medium to dark gray conglomerate of black phosphatic pebbles, for the most part small, but ranging up to an inch in diameter. Commonly the upper surface of the sandstone is marked by small bosses of iron-cemented sand.

Distribution and Thickness

The Turpin ranges in thickness from an inch or less to as much as 15 inches and possibly more. It is likely that it is missing over short distances, but I have observed no place where the base of the Grassy Creek is well-exposed and a zone of an inch or more is not to be assigned to this unit. In general the greater thickness is at the heads of the ravines cutting the Mississippi River bluff in the vicinity of sec. 35, T. 54 N., R. 1 W., in Pike County, Missouri. Good outcrops occur in the heads of several hollows in the SW sec. 33, T. 53 N., R. 1 E., southeast of Clark's Mill. The conglomeratic facies is conspicuous in exposures on Grassy Creek in the NW SE sec. 19, T. 54 N., R. 2 W., in Pike County. The Turpin, as the Grassy Creek, is confined to the area northeast of the Lincoln Arch.

Paleontology

The only indigenous fossils that have been found in the Turpin are conodonts. These are not abundant, but may be expected in sufficient quantity for identification.

Age and Correlation

There can be no question of the Devonian age of the Turpin. In it have been found such typical paragenera as *Palmatolepis, Polylophodonta, Ancyrognathus* and *Icriodus*. Fully as important is the fact that in the sandstone no Mississippian forms such as *Siphonodella, Elictognathus* or *Pseudopolygnathus* have been identified. The conodont fauna clearly indicates an upper Devonian age comparable to that of the Hardin of Tennessee and eastcentral and southeastern Missouri, and the Roaring River sandstone of southwestern Missouri. When all these and other late Devonian conodont faunas are studied in detail it may be possible to make a more nearly exact correlation.

Recommendation

I recommend that the Turpin sandstone be designated as the basal member of the Grassy Creek.

The Saverton Shale

Name

The name Saverton comes from a village by that name in northeastern Ralls County, Missouri (SE sec. 18, T. 56 N., R., 3 W.). It was proposed by Keyes (1913, pp. 160–162) for the upper part of the "black and green" shales beneath the Louisiana limestone at Louisiana as follows:

> Immediately beneath the Louisiana limestone at the original locality are two feet of blue shales. This apparently insignificant layer is usually included in the Grassy Creek black shales below. It now seems to have much greater importance. Northward from Louisiana these shales rapidly become thicker.

This proposal seems to have been accepted generally and the characteristic features and the distribution of the Saverton were discussed in some detail by Moore in 1928 (pp. 37, 38). However, Branson and Mehl (1933 A, p. 174) concluded that the blue shales of the "Saverton" represent the upper weathered part of the Grassy Creek and they suggested that the name Grassy Creek be used as it was originally by Keyes.

In 1935 J. Weller saw no reason for separating the blue from the black shales and proposed that together they be known as the Saverton shale. Neither of these proposals seems to have gained general acceptance and current practice in assembling stratigraphic data generally follows Keyes' proposal of separation.

Type Locality

Regardless of the fact that Keyes named these shales "Saverton", the original locality described by him (1897, p. 63) is as follows:

> Immediately beneath the well defined Louisiana limestone, in the vicinity of Louisiana, there are about six feet of black and green shales carrying a characteristically Devonian fish fauna.

The type locality therefore is here designated specifically as the Missouri River bluff several hundred feet above the Champ Clark bridge, the same as the type locality for the Grassy Creek (SW NW NE sec. 18, T 54 N., R. 1 W.).

Distribution and Thickness

Outcrops of the Saverton are essentially coextensive with those of the Grassy Creek; in Missouri confined to the northeastern part of the state north of the Lincoln Arch; in Pike, Ralls, and Marion Counties with some possibility of exposures in Lincoln County. In Pike County the average thickness is probably little more than 2 feet and somewhat less in the vicinity of the type locality. In the SW NE sec. 18, T. 54 N., R. 1 W., the thickness is about 8 inches. On Grassy Creek some miles to the west a thickness of 15 feet has been reported (Branson and Mehl, 1933 A, p. 173, fig. 2). In Ralls County, with outcrops centering around the New London area, the thickness ranges from a few inches to not more than 2 or 3 feet. The Saverton seems to thicken materially toward the northwest. Moore (p. 37) reported 100 feet of Saverton shale in the river bluff near Saverton in Ralls County, but it is likely that the Saverton, as herein defined, is much less. On Sees Creek, west of Hannibal in Marion County (NE sec. 22, T. 57 N., R. 7 W.) Branson and Mehl measured 15 to 20 feet of shale between the Louisiana and the Mineola (Callaway). This shale, which they designated as Grassy Creek, I now believe to be Saverton.

Lithology

The Saverton is a blue or greenish gray silty shale; somewhat fissile, but readily weathering to unctuous, sandy clay. In places one or more thin beds of sandstone appear in the section. The upper part, a few inches to a foot or more thick, is blue-green, calcareous, blocky siltstone in many places.

Stratigraphic Relations

There is a sharp break between the lithology of the Saverton and that of the underlying Grassy Creek, but there is no other marked evidence of unconformity although the relationship on Sees Creek in Marion County described above may be so interpreted. Above, the Saverton appears to grade into the overlying Louisiana in some places. However, these exposures are limited and the relationship may be questioned. In Pike County, SE SE sec. 35, T. 54 N., R. 3 W., the Louisiana is missing and the Saverton is overlain by the Hannibal.

Paleontology

Most of the fish remains described from the Grassy Creek are from the "upper green part", probably the Saverton. Conodonts are "patchily" but abundantly distributed in the Saverton, but to date no comprehensive list that is dependable is available. As pointed out elsewhere most of the forms described by Branson and Mehl as Grassy Creek occurrences came from the Saverton. Several minor unpublished lists indicate that the "Grassy Creek" list of Branson and Mehl is, with minor exceptions, a fair picture of the Saverton fauna. In the upper part of the Saverton, at several places, a fairly small variety of brachiopods may be found. One such place is at Louisiana on Town Branch, a locality marked by a seasonal spring.

Age and Correlation

Late Devonian age must be accepted for the Saverton. Its close relationship with Grassy Creek is evident. No representative of the several form-genera of conodonts that mark the earliest Mississippian in North America and Europe has been reported in the Saverton. On the other hand, representatives of the several typical Devonian groups that do not appear in any sediments of undisputed Mississippian age are abundant. Although there are many similarities between the faunas of the Saverton and the Sweetland Creek, there are several distinctive forms in the latter that seem to set it apart. Before more data are available opinions should not be given too much weight, but at present the Saverton appears to be somewhat older than the Holts Summit and most closely related to the Maple Mill of Iowa.

The Louisiana Limestone

Name

The name Louisiana was first used by Keyes (1892, p. 282) for the limestone succession in Missouri that had been known previously as the "Lithographic Limestone." This latter designation was suggested by Swallow in 1855 (p. 105).

Type Locality

Not only does the name suggest the close vicinity of Louisiana in Pike County. Missouri, as the type locality, but the thickness and relationships described by Keyes (1892, p. 286) under the general heading, "Louisiana Exposures" shows clearly that this was his intent.
To quote (p. 289):

> Swallow's Lithographic Limestone is exposed best perhaps at Louisiana in Pike County, Missouri, where it attains a maximum thickness of more than 60 feet.

Distribution and Thickness

Outcrops of the Lousiana in Missouri are confined to a fairly wide irregular band that roughly parallels the Mississippi River to the northeast of the Lincoln Arch in Pike, Ralls, and Marion Counties. From subsurface data it has been identified in adjacent parts of Lincoln, Monroe, Shelby, Lewis, Knox, Clark, and Scotland Counties. From its thickest exposures near Louisiana in northeastern Pike County the limestone thins in all directions.

Lithology

The Louisiana consists typically of beds of dense limestone that vary from 2 to 18 inches in thickness with an average of about 6 inches. Between the typical pale buff lithographic-like beds are commonly interlocated "weathered" zones of brownish yellow earthy calcareous material.

Stratigraphic Relations

The Louisiana limestone in Missouri rests unconformably on the Saverton shale, the unconformity evidenced primarily by the markedly varied thickness

of the latter. It is likely that in some places the Louisiana rests directly on the Grassy Creek. It is reported by Krey (plate IX, fig. A) to rest on Devonian limestone near Hardin, Illinois. The upper surface of the Louisiana is very irregular with the Hannibal shale in contact with a considerable number of the zones that are recognizable in the limestone. In a limited area in northeastern Pike County there intervenes a 4 to 12 foot thickness of black fissile shale and sandstone between the Hannibal and the Louisiana. This is described elsewhere in this report as the Cuivre formation.

Paleontology

Although in general fossils are only sparsely distributed through the Louisiana, some beds at scattered localities have contributed a considerable variety of invertebrates such as has been described by Williams. One of the most promising fields is that of micro-organisms, including megaspores. Although repeated sampling in many places over a considerable period of time has failed to increase materially the meager conodont fauna listed by E. B. Branson (1938B, p. 179 and 1944, p. 173) the fact that conodonts have been found encourages further investigation. In the course of field sampling Walter Niewoehner has built up a large collection of microcrinoids and ostracodes from the Louisiana. Sporangites occur in considerable abundance in the shaly partings of the Louisiana limestone.

Age and Correlation

If one were to accept as valid identifications of Maple Mill and Louisiana as presented in "Correlation of the Mississippian Formations of North America" (J. Weller et al.), there would be no question concerning the age of the Louisiana. Thomas (pp. 407, 408) has given conclusive evidence of the late Devonian age of the Maple Mill based on an extensive study of its conodonts. In the reference to correlation cited above, the Maple Mill is shown overlying the Hamburg and the Louisiana. It must be concluded that adequate identification data were lacking. Otherwise it is not likely that the Maple Mill or earlier strata would be correlated with any part of the Hannibal.

Age assignment of the Louisiana invertebrates is a matter of opinion. Admittedly the fauna is unique, with elements that bespeak both Mississippian and Devonian affinities. In 1933 Branson and Mehl (1933A, p. 182) concluded as follows:

> . . . it is noteworthy that the Louisiana fauna of invertebrates is more closely related to Devonian than to Mississippian.

However, in 1943 J. S. Williams, with this same fauna, concluded that the Louisiana was Mississippian in age. The ostracodes, too, have failed to give conclusive evidence of the age of the Louisiana. According to Niewoehenr (personal communication) who has not completed his study, there are too many new forms to permit satisfactory correlation; and according to Koenig and Niewoehner a new genus of microcrinoids from the Louisiana is of late Devonian or very early Mississippian age. The peculiar "loop-bearing" brachiopods from the Louisiana, described by Unklesbay and Niewoehner, give no additional evidence as to age.

The evidence of the conodonts is more positive. In 1944 Branson listed the conodonts that had been identified in the Louisiana (p. 173). In this compilation are listed twelve genera, four of which (*Ancyrognathus*, *Icriodus*, *Palmatolepis*, and *Polylophodonta*) have not been recorded correctly in any formation of undisputed Mississippian age. On the other hand, none of the several genera such as *Siphonodella*, *Elictognathus*, *Pinacognathus*, and *Pseudopolygnathus*, that are typical of the lower Mississippian, appears in the list.

Another fossil record that argues strongly for the Devonian age of the Louisiana is the abundance of sporangites in the clay partings of the limestone. The great majority are featureless spheres lacking the spore coat, but the preservation of some specimens is such as to make the identity of the spheres certain. It should be noted that sporangites (*Tasmanites* and related forms) have not been identified in strata of undisputed Mississippian age.

The Louisiana is commonly correlated with the McCraney limestone of Illinois, presumably because of the marked similarity of the lithologies of the two.

The Noel Shale

Name

The name Noel was proposed in 1904 by Adams (p. 24) as a substitute for "Eureka" (preoccupied) for the black shale beneath the St. Joe limestone in southwestern Missouri and northwestern Arkansas. The name is that of a town in McDonald County, Missouri.

Type Locality

The Eureka shale, for which the name Noel shale was substituted, was named for Eureka Springs in Carroll County, Arkansas. The type locality for the Noel is here designated as about one-half mile south of Noel which Moore (p. 115) designated as the place of greatest thickness of the shale observed in the vicinity of Noel.

Thickness and Distribution

In Missouri, from its maximum thickness in McDonald County the Noel thins rapidly toward the north and east. The greatest thickness reported is 50 feet on Sugar Creek in the southeastern corner of the county, recorded by Marbut (1894, p. 386). The greatest thickness I have noted in McDonald County is somewhat more than 35 feet measured in the NW NW SE sec. 16, T. 22 N., R. 30 W. In Barry County on Roaring River (SW NE sec. 34, T. 22 N., R. 27 W) the black shale measures 21 feet and 3 inches. The average in these two counties is probably less than 10 feet. Other exposures toward the north and east are thin and widely scattered and are a few inches or a few feet thick. Small patches of the Noel have been noted in Christian and Greene counties. At one time, possibly early in the 1930's, I noted a small exposure of black shale at the south of a small tributary to Whetstone Creek, north of Williamsburg in Callaway County. This, and black shale in deep wells north of Columbia in Boone County, I take to be remnants of Noel.

Lithology

The Noel is a very dark gray or black, hard, fissile clay shale with little or no sandy zones excepting a basal sandstone member described below. The shale weathers to small thin plates and in the process releases small pyrite nodules, scattered in short, isolated bands.

Relationships

The Noel (including the basal sandstone member) is unconformable below. In southwestern Missouri it rests on the Cotter dolomite, for the most part. In Barry County, over limited areas, it rests on the middle Devonian Fortune formation. At some places in McDonald County the basal sandstone is missing and the black shale rests on the Cotter. The Noel is unconformably overlain by Mississippian strata ranging in age from the oldest Kinderhookian to the early Osagean. In Christian County, over a limited area on the James River, the black shale is missing (SW SE SW sec. 29, T. 27 N., R. 22 W); and basal Mississippian sandstone rests on the basal sandstone of the Noel. A short distance up stream a thickness of eight to ten inches of black shale intervenes.

Paleontology

The most varied fauna that has been reported for the Noel is the meager fauna recorded by S. Weller (1901, p. 131) from exposures in Christian County. The fauna includes four species of brachiopods, one crustacean, and some fish scales. Conodonts are very sparsely distributed throughout the black shale. However, these may be missed, regardlesss of the time spent in searching. At various places conodonts seem to have been concentrated and may be collected in abundance in the weathered upper part of the shale, possibly materials that have been reworked. Most, if not all, such concentrations constitute Devonian admixture in a Mississippian fauna, and the identity of the admixture source may be questioned. One such occurrence, in the SW SE SW sec. 14, T. 22 N., R. 31 W., is interpreted as admixture derived from the Noel. Conodonts from a locality in Christian County east of Boaz (sec. 29, T. 27 N., R. 22 W.), in a pit that had been dug on the flat of the James River, are similarly interpreted. The collections from both localities contain many well preserved, typically upper Devonian forms along with basal Mississippian conodonts.

Age and Correlation

Regardless of how the conodont occurrences in the weathered zone at the top of the Noel are interpreted, the youngest possible age range of the shale is limited to the upper Devonian because of the immediately overlying basal Mississippian faunas in many localities. Below, the basal sandstone fauna limits the age to the upper Devonian.

In much probability the Noel is in part equivalent to the Grassy Creek, the upper new Alvany and the Chattanooga.

The Roaring River Sandstone (New)

Name

The name Roaring River comes from the stream by that name in the southern part of Barry County, Missouri. The name is applied to a sandstone that crops out on the valley sides of that stream.

Type Locality

The type locality for the Roaring River sandstone is designated as about the center of the east side of sec. 34, T. 22 N., R. 27 W., Barry County, Missouri, along Missouri State Highway 112. This locality is chosen from the many exposures in this part of the state because the relationships are well-exposed and the outcrop gives promise of ready accessibility and little change over the years.

Lithology

In fresh exposures the Roaring River is light gray to pale buff, but becomes medium or dark reddish-brown on weathering. It is predominantly quartz sandstone with calcium carbonate cemented grains of medium or small size. In some places the cement is siliceous. The grains are predominantly well-rounded, but in some places regrowth has developed crystal faces. Conglomeratic facies are not typical, but granules of chert, dolomite and hard clay are common in the lower part. Worn fish teeth and plate fragments occur in some places.

In most places the sandstone consists of a single bed but it may consist of two or more units. In such cases the bedding is irregular, but cross-bedding is not conspicuous. An unctuous, blue-gray, sandy clay about an inch thick commonly occurs at the top, and probably should be included.

Distribution and Thickness

The Roaring River may be expected coextensive with the Noel shale, but in general it seems to be confined to the southwestern part of the state. The best development is in McDonald and Barry Counties. There are limited areas here, however, where the sandstone is absent and the Noel rests directly on Ordovician strata. In a small stream valley about one-fourth mile north of Powell, in the SW sec. 16, T. 22 N., R. 30 W., the Noel rests on the Cotter dolomite with no evidence of a sandy zone at the base. No Roaring River has been noted in central Missouri, although there are a few outcrops of the Noel (northeastern Callaway County) and the black shale is encountered in one or more deep wells in northern Boone County.

At the type locality the sandstone consists of two irregular beds that total 9 to 12 inches. A short distance to the north (SW SE sec. 27, T. 22 N., R. 27 W.) along State Highway 112 the thickness is 16 to 18 inches, the upper half consisting of bluish-gray, sandy clay. In McDonald County at the north edge of Powell (NW NW SE sec. 16, T. 22 N., R. 30 W) the Roaring River consists of one or more beds of sandstone totaling 3 to 5 inches with a thin, gray, sandy clay at the top. In a small stream in NW NW sec. 14, T. 22 N., R. 30 W., the section consists

of 2 to 4 inches of pale buff sandstone containing chert and phosphatic pebbles with 6 to 8 inches of dark, greenish-gray, clay shale at the top.

Relationships

The Roaring River sandstone rests unconformably on a variety of formations involved in a surface that appears to have presented very slight relief. Most commonly the immediately underlying rock is Cotter dolomite, but in the SW sec. 4, T. 23 N., R. 26 W., on Fortune Branch of Rockhouse Creek in Barry County, it rests on the chert of the middle Devonian Fortune formation. The Roaring River seems to be conformable with the overlying Noel shale. In places where the sandstone is absent basal relationship of the shale is interpreted as the result of nondeposition of the sand on an area of slight elevation above the essentially flat plane of deposition.

Paleontology

Aside from broken and abraded pieces of fish teeth and bone the only fossils that have been noted in the Roaring River sandstone are conodonts. These occur at least sparingly in most outcrops and fairly abundantly in some places. They are most abundant in the sand facies, but may be expected in the sandy clay zone that commonly marks the top.

Age and Correlation

There can be no doubt concerning the Devonian age of the Roaring River. Most of the typical Devonian conodont forms such as *Palmatolepis*, *Icriodus*, *Ancyrodella* and *Ancyrognathus* are represented at nearly every outcrop. More important, perhaps, is the fact that none of the typical early Mississippian forms such as *Pseudopolygnathus*, *Siphonodella* and *Elictognathus* have been found. Attempts have been made to zone the upper Devonian of North America on the basis of conodonts, but our present knowledge of environmental influences is too meager and our practices in speciation are too varied to warrant unqualified acceptance of such schemes. It is obvious, however, that the conodont fauna of the Roaring River is not markedly different from that of the Hardin of Tennessee and east central Missouri or that of the sands at the base of, and within the black shale of, northwestern Arkansas.

Recommendation

The Roaring River is described apart from the Noel black shale because the sandstone contains fairly abundant conodonts, and, therefore, offers the possibility of close correlation. Although the sandstone appears to represent the initial sedimentation of the overlying black shale, it is possible that the relationship is unconformable. I recommended that the Roaring River sandstone be considered a member of the Noel shale.

The Term Kinderhook

The term Kinderhook was defined by Meek and Worthen in 1861 (1861 B, p. 288) as follows:

The name "Kinderhook group" is now proposed by the authors to include the beds lying between the Black slate and the Burlington limestone, which have hitherto been considered the equivalents of the Chemung group of New York . . .

These authors (1861 A, p. 170) gave the following generalized section (not that at Kinderhook) to illustrate the relationships of the units involved:

1. Burlington limestone attaining a thickness of..... 200 feet
2. Chouteau limestone..... 100 feet
3. Vermicular sandstone..... 65–100 feet
4. Lithographic limestone (rather local)..... 60 feet
5. Black slate..... 30–40 feet
6. Hamilton group..... 120 feet

If the "lithographic limestone" of the above is interpreted as the Louisiana, this section corresponds closely with the current conception of many stratigraphers concerning the Kinderhook. Some would omit the Louisiana and others would include the "black slate" (Saverton-Grassy Creek).

The section at Kinderhook differs in several respects from the illustration given by Meek and Worthen. The succession exposed on McCraney Creek, a short distance north of Kinderhook, Illinois, was recorded by Moore (p. 21) as follows:

	Thickness (feet)
Drift and loess	
Osage group	
Burlington limestone (Lower)	
4. Limestone, gray coarse crystalline, crinoidal, massive. Exposed	20
Disconformity	
Kinderhook group	
Hannibal formation	
McKerney (McCraney) limestone member	
3. Limestone, bluish drab, fine-grained, compact, with sharply conchoidal fracture, slightly irregular bedding and partially altered to brown, magnesian limestone	6
English River (?) sandstone member	
2. Sandstone, blue, weathering green and brown, very fine-grained, massive, calcareous, fossiliferous. Weathers characteristically along joint planes obliquely inclined to bedding	42
Maple Mill (?) shale member	
1. Shale, blue, shaly, argillaceous, fairly uniform in texture, containing thin sandstone beds in the upper part. (May include part of Saverton shale in lower part.) Exposed	43

The section described by J. M. Weller (1941, pp. 72, 73) in the NE sec. 15, T. 4 S., R. 7 W., a short distance north of the above section, differs from it only in minor details of thickness. Both include the Maple Mill in the Hannibal. In the light of present information, the incongruity of defining either the Hannibal or the Kinderhook, as is implied by both sections, is obvious. Through the work of Thomas (1940, p. 408) and others the Devonian age of the Maple Mill has been established.

E. B. Branson (1938 A, p. 5) proposed that "Lower Mississippian" be substituted for the term Kinderhook, but this proposal has not been accepted generally.

Recommendation

If the Louisiana limestone is Devonian, as is believed by some stratigraphers, and is the equivalent of the McCraney, as is maintained by some, there is the possibility that no strata of Mississippian Kinderhook age are exposed at Kinderhook. Confusing as the name has been and incongruous as it may prove to be, the term Kinderhook, through long use, deserves a place in Mississippian stratigraphy. If the term is interpreted in the broad sense in which it was originally proposed, there is no necessity for a new name or the designation of a type locality. I propose that Kinderhook be used to designate all strata of Mississippian age that are older than the Osage.

The Terms Easley Group and Fabius Group

J. Weller et al. (p. 101) proposed that the Kinderhook be considered a series and be divided into two groups, the Easley and Fabius. The Easley was to include "all Kinderhookian strata which are almost universally recognized to be of Mississippian age" and the Fabius group should include "those Kinderhookian strata which are believed by some to be Mississippian but by others to be Devonian." The position of the committee in establishing two Kinderhook groups based on the above distinction does not appear tenable. The selection of names is ill-advised if they are intended as locality designations where details of the Easley and Fabius groups may be studied.

Recommendation

I recommend that the terms Easley group and Fabius group be dropped from the list of stratigraphic designations in Missouri. If there is no doubt of the Mississipian age of a unit that is older than Osage it may be called Kinderhook in age and, with somewhat more refinement, it may be designated as early or late Kinderhookian.

The Bachelor Formation (New)

Name

The term Bachelor formation is proposed for a basal Mississippian sandstone that cuts across time zones ranging in age from the oldest Mississipipan to as late as early Osagean.

Type Locality

The Bachelor formation is well developed in many exposures to the east, west and south of Bachelor in the northeastern part of Callaway County, Missouri. The exposure in the SE NW SW sec. 9, T. 48 N., R. 8 W., is designated as the type locality because of its accessibility and its marked variation over short lateral distances. An excellent section for comparison occurs on the east side of sec. 2, T. 48 N., R. 8 W., where the north-south road crosses a branch of Whetstone Creek.

Distribution and Thickness

To the northeast of the Lincoln Fold in Ralls, Pike, Marion and Lincoln Counties, Missouri, repeated search has failed to discover strata that can be interpreted as Bachelor. With this exception, starting immediately adjacent to the Cap-au-gris fault, wherever the base of the Mississippian is exposed, some facies of the Bachelor is seen to begin the Mississippian sedimentation. As is pointed out later, the oldest facies is widely distributed across the state and seems to represent a very limited time differential. This zone, the "Siphonodella zone", will be treated as a distinctive unit in later paragraphs.

Over most of its extent (including the Siphonodella beds) the thickness of the Bachelor is to be measured in inches rather than feet. In Callaway County the average thickness is perhaps less than 2 feet, but in east central Callaway and western Montgomery counties thicknesses of as much as 8 to 10 feet may be found.

Lithology

The lithology of the Bachelor, excluding its Siphonodella zone, is markedly varied although it consists dominantly of pale buff quartz sandstone of medium grain size, moderately well to poorly sorted. The exposure south of Fulton in Callaway County, SW NE NW sec. 33, T. 47 N., R. 9 W., is typical of this general area. Here, overlying Snyder Creek shale, a bed of greenish-yellow fucoidal sandstone, 4 to 12 inches thick, is followed by a bed of hard, dense, medium gray, highly arenaceous limestone or highly calcareous sandstone, about 12 inches thick. This is overlain by Burlington limestone.

Farther west, some 10 or 12 miles, it is a massive sandstone varying from 2 to 30 inches thick. Near Reform on a branch of Logan Creek, E½ SW sec. 5, T. 46 N., R. 7 W., the section totals nearly 4 feet thick, a lower sandstone 11 inches thick followed by a shaly zone of about 16 inches and an upper sand unit of 18 inches or more. Farther toward the north the Bachelor most commonly consists of sandstone from a few inches to as much as 6 to 8 feet thick. In most places the basal part of the Bachelor (excluding the Siphonodella zone) is marked by an abundance of phosphatic nodules that are more or less spherical or flattened, irregular and elongate, and which measure up to several inches in greatest diameter. The distribution of these phosphatic nodules is well illustrated on Cow Creek, Callaway County, in the NE NE NW sec. 25, T. 47 N., R. 8 W.

Paleontology

In only a few places has the Bachelor (other than the Siphonodella zone) produced fossils sufficient for satisfactory stratigraphic determination. At one locality, SW½ sec. 5, T. 46 N., R. 7 W., near the village of Reform, the shaly facies yielded a conodont collection that suggests late Kinderhook or early Osage in age for that locality. The Burlington immediately overlies the Bachelor here. A considerable brachiopod fauna was obtained from a highly calcareous sandstone near the top of the formation in the SE SW SE 11, T. 45 N., R. 11 W. This

suggests upper Chouteau age for this locality. The Bachelor here is overlain by 8 to 10 feet of Chouteau. In several localities the most conspicuous megafossils are high spired gastropods too poorly preserved for satisfactory identification.

Stratigraphic Relations

In all the many places observed the Bachelor is separated by marked unconformity from the underlying strata. Not only is this evident in the varied age of the subjacent beds, ranging from Jefferson City Ordovician to the late Massie Creek, but the lower surface of the formation is markedly irregular in most exposures and is most commonly set off by a conspicuous band of phosphatic nodules. In general the Bachelor appears to be conformable with the overlying beds, initiating the Mississippian sedimentation at every locality regardless of the fact that over a considerable area the formation cuts across time zones.

Age

It is obvious that age for the formation as a whole cannot be limited more closely than earliest Mississippian to early Osage, although at the various localities a precise age equivalency may be expected.

The Siphonodella Zone (New)

Name

The name Siphonodella zone is proposed for the oldest part of the Bachelor formation. This is very widespread and has a unified conodont fauna that apparently marks almost exact time equivalence from place to place. The name comes from the most conspicuous form-genus in the assemblage, *Siphonodella*. The zone records the first appearance of this and several other form-genera such as *Elictognathus*, *Pinacognathus*, and *Pseudopolygnathus*, in North America. It should be pointed out that the Siphonodella zone does not include all the strata in which the form-genus *Siphonodella* is found, for it has a considerable vertical range. In general the zone includes only those strata within the range of the typical development of *Siphonodella sexplicata*.*

Type Locality

Localities for excellent collecting in the Siphonodella zone are so numerous and widespread over Missouri that it is difficult to designate a single locality that is illustrative of all aspects. In St. Charles County (SW NW NW sec. 24, T. 46 N., R. 1 E.) in a small gully tributary to Dardenne Creek, there is promise of permanency of outcrop and accessibility of a complete section, which is therefore designated as the type locality.

Distribution and Thickness

Except for places within the general area of Callaway, Boone and Montgomery Counties where the older part of the Bachelor is absent, and excepting Marion,

* This is meant to exclude several identifications of the species as indigenous to middle or late Kinderhook times.

Ralls and Pike Counties and the part of Lincoln County northeast of the Lincoln Fold, wherever the base of the Mississippian is exposed, one may expect to find the Siphonodella zone. The outcrops form a very irregular arcuate pattern about the northern and western sides of the Ozark uplift. In general the pattern parallels the Missouri River from the Mississippi at Louisiana, westward to Ralls County, thence to the southwest corner of the State into McDonald, Barry and Stone Counties. There are, of course, local exceptions to this generalized distribution, conspicuously some places in Jefferson, St. Louis and St. Charles Counties, where this oldest part of the Bachelor is absent.

The thickness, remarkably uniform over most of its outcrop, varies from 2 or 3 inches up to a foot or more in a few places. In very limited areas as much as 4 feet has been measured where the oldest part of the Bachelor occurs. I have found no exposures where more than 5 or 6 feet would be assigned, with reasonable certainty, to the Siphonodella zone. At the type locality the thickness varies in a very short distance from 10 inches to perhaps 6 feet. Near Danville, in Montgomery County, NE NE NW sec. 25, T. 48 N., R. 6 W., it is about 24 inches thick. Four miles to the north, in part of the McLane Quarry on Clear Fork, the thickness is about 4 feet.

Lithology

Over most of its extent the Siphonodella zone consists of a few inches on greenish yellow sandy clay or sandy clay shale. Lenses of calcareous sandstone, in most places hard and thoroughly cemented by calcite, are common. These lenses are water green in color and break along crystal cleavage planes. The reflection of light from these planes is noticeable and has lead to the designation "glint sand." This glint sandstone is not confined to the Siphonodella zone but seems to be fairly characteristic of it. In places there is little shale, a continuous sandstone bed making up the thickness. In most places where sandstone predominates it may reach a thickness of as much as 30 inches. Over much of its extent, particularly toward its westward development, it is conglomeratic at the base. This includes chert and other pebbles derived from subjacent strata. Phosphatic nodules, up to an inch or more in greatest diameter, are common in the lower part.

Relations

The Siphonodella beds are unconformable on strata ranging in age from Cotter or Jefferson City to Glen Park or Massie Creek. This relationship and the marked faunal break constitute one of the greatest stratigraphic breaks in the Missouri Paleozoic column.

Paleontology

At almost every outcrop the Siphonodella beds contain conodonts in abundance. This conodont fauna is the assemblage that Branson and Mehl (1933B) mistakenly called Bushberg. In its typical development it includes *Siphonodella sexplicata*, *S. quadruplicata*, *S. duplicata*, *S. lobata*, one or more species of *Elictognathus*, and a variety of *Pseudopolygnathids*. Ostracodes of considerable variety have been described by Morey from the Siphonodella zone ("Bushberg") near

Williamsburg in Callaway County; and from the same locality and outcrop Peck has described a variety of charaphytes.

The megafauna described by E. B. Branson (1938A, pp. 159–183) from the "Bushberg" near Danville in Montgomery County may have come from the lowest beds in the Siphonodella zone; but I have not been able to verify this. I found many elements of the *Siphonodella* conodont fauna, and a limited number of brachiopods, in the McLane Quarry mentioned above. These fossils came from the lowest part of the Siphonodella zone, a massive glint sandstone about 4 feet thick. It was exposed in an exploratory pit in the quarry floor and is at present covered by water.

Age and Correlation

The Siphonodella zone is a distinctive faunal zone in the oldest part of the Bachelor formation. The fauna seems to represent the oldest Mississippian in North America. The zone is the "thin greenish arenaceous band" of Meek (p. 175 and fig. 15) at the base of the Chouteau in central Missouri, the zone that came to be designated mistakenly as "Sylamore" and later as "Bushberg". It has been recognized at the base of the Mississippian in scattered areas over much of the United States and Canada, both in outcrops and in deep wells. In tracing this zone across Missouri and elsewhere one finds in it an admixture of conodonts that reflects the age of the subjacent beds. The Devonian conodont "pick up", for instance, varies in indirect proportion to the distance from Devonian strata. Over large areas the strata subjacent to the Siphonodella zone are lower Ordovician in age. In such places, almost without exception, there is a marked admixture of Ordovician conodonts in the *Siphonodella* fauna. For the most part the admixture is evident through differences in color, sheen, fragmentation and wear, but in places well preserved specimens of an earlier age are found in the *Siphonodella* conodont assemblage.

Elsewhere the conodonts of the Siphonodella zone are discussed in relation to European faunas.

The Cuivre Shale (New)

Name

The name Cuivre shale is proposed to designate a stratigraphic unit between the Hannibal shale and the Louisiana limestone in Pike County, Missouri. The name comes from Cuivre Township, near the northeastern corner of which the type locality is located.

Type Locality

The type locality for the Cuivre is designated as the SE NE SE sec. 35, T. 54 N., R. 3. W., Pike County, Missouri, about 4.5 miles north of Bowling Green. Here, in one of the head branches of Grassy Creek, is exposed, in a comparative short distance, the entire thickness of the unit.

Distribution and Thickness

The Cuivre shale has been identified with certainty in only two localities, but it is expected that a considerably wider distribution will be found. In addition to the exposures at the type locality, where outcrops extend along the creek for about a half mile, the shale has been identified about 6.5 miles to the east and about a mile north, in a recent road cut. This is near the Stark Nurseries, in the SE SW sec. 25, T. 54 N., R. 2 W., Pike County, Missouri. The greatest thickness observed is at the type locality where a thickness of 12 feet has been measured. At the second locality only 4 to 6 feet is assigned to the Cuivre.

Lithology

The Cuivre consists predominantly of very dark gray to blue-black, somewhat fissile, clay shale. In some places it is massive and shows blocky weathering. At its base, it is distinctly sandy and in its midst there appear lenses of hard, gray sandstone with calcareous and pyritiferous cement. One of the lens zones can be traced for a considerable distance as a rust band on the weathered surface. At the type locality one lens averages 4 inches in thickness. The upper surface is pitted by current ripple marks. Some lenses are from a few inches to 2 or 3 feet wide and reach a length of ten to fifteen feet in the direction of the current flow. The upper surface of most of the sandstone lenses is coated with botryoidal pyrite.

Stratigraphic Relations

The Cuivre is unconformable below, resting on the Louisiana or the Bowling Green limestone in the two places where the contact is exposed. The upper relation seems to be unconformable beneath the Hannibal although the evidence is not conclusive. There is a sharp line between the typical color and lithology of the Hannibal and that of the dark, fissile shale of the Cuivre at the type locality; and there are stringers of color extending from the Hannibal into the Cuivre.

Paleontology

Conodonts have been found in considerable abundance in most of the sandstone lenses and in the sandy zones. These fossils are well preserved and show no sign of transportation although it must be assumed that they were segregated in the sand from a much wider area. They are very meagerly scattered in the immediately associated shale. In addition to the conodonts an appreciable number of very small spiriferoids and other brachiopods, most of them broken, are found in the sand lenses. There is little to indicate that there were larger forms.

Age and Correlation

There can be no question concerning the Mississippian age of the Cuivre. Among the conodonts the paragenera *Pseudopolygnathus* and *Siphonodella* are most abundantly represented. *Elictognathus* and a form intermediate between this and *Pinacognathus* are well represented. Numerous other less restricted forms such as the Polygnathids, Hindeodellids, Spathognathodids and Prioniodids are well

represented. It should be noted that the typical basal Mississippian *Siphonodella sexplicata* has not been found. As is to be expected, the underlying rocks have contributed admixtures. This is particularly evident in the large number of middle Devonian specimens of *Icriodus latericrescens*. Few other typically Devonian forms are associated.

Age and Correlation

The conodont fauna is closest to that of the Hannibal as described by E. R. Branson. The brachiopod fauna includes some forms that are found in the Glen Park, but the resemblance of the two faunas is little more than enough to stimulate study of both. I have been unable to identify the Cuivre in Illinois sections where the lower part of the Hannibal is exposed.

PART III

BASAL MISSISSIPPIAN RELATIONSHIPS BY REGIONS

Northeastern Missouri

During the late Devonian-early Mississippian times northeastern Missouri, that part of the state to the north and east of the Lincoln Arch, constituted a distinct province. This seems to have had no interchange with the interior of the state, excepting possibly by a circuitous path through northwestern to southwestern to central Missouri. Among the unique features of the northeastern

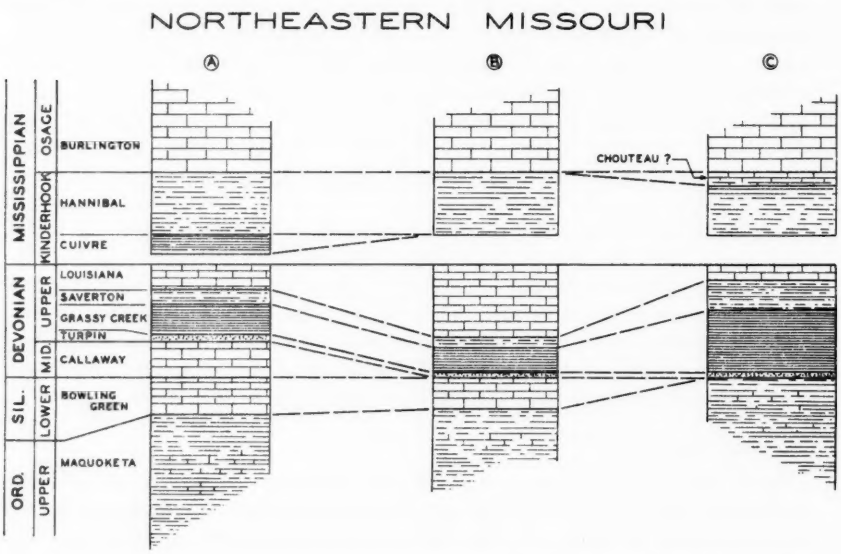

FIG. 3. Geological sections to show various relationships at the base of the Mississippian in Northeastern Missouri. All are generalized; but sections A, B and C represent the areas northwest of Bowling Green, the vicinity of Louisiana and eastern Pike County, respectively.

province should be mentioned the absence of records of the oldest Mississippian, the Siphonodella Zone of the Bachelor, bespeaking a somewhat delayed entrance of the Mississippian sea into that area. The Hannibal of northeastern Missouri has much in common with the Northview of the southeastern part of the state. In addition to the "caudi galli" markings (*Taonurus*) in each, the conodonts of the two formations have much in common; but exact correlation has not been made.

Insofar as the upper Devonian is concerned, the Louisiana has no certain correlative in other parts of Missouri. It is generally believed that the Grassy Creek is equivalent, in part, to the Noel of southwestern Missouri. When studies of the conodonts of the Turpin and Roaring River sandstone members are completed it is likely that more nearly exact correlations can be made.

Figure 3 shows the various relationships of the "boundary formations" in northeastern Missouri.

Eastcentral and Southeastern Missouri

During upper Devonian and lower Mississippian times the differences in the "boundary formations" of other regions of Missouri seem to be differences of

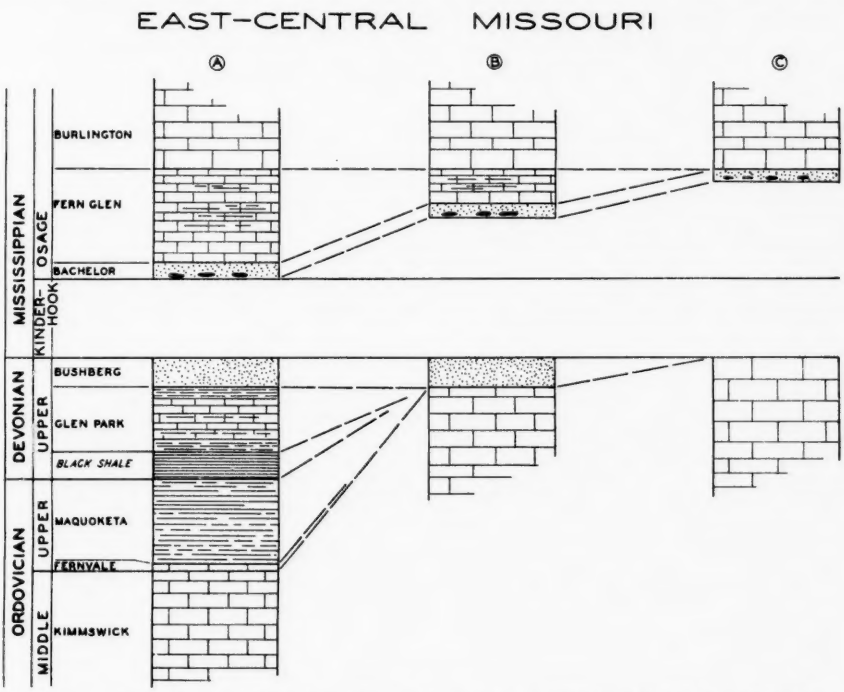

FIG. 4. Generalized geological sections to show different relationships of the Mississippian in Eastcentral Missouri. Sections A and B indicate marked differences in closely adjacent localities in Jefferson County. The essentials of section C may be duplicated at several places in St. Louis County.

sediment sources and the nature of adjacent land areas rather than the result of isolation. These deposits in eastern central and southeastern Missouri are very much alike, differing only in minor details. A low, oscillating land area seems to have intervened between the eastern central and central Missouri areas during most of the time and this seems to have confined the Glen Park, and possibly the Bushberg, to the eastern side. The oldest of the Devonian, the black shale, conspicuous in many places in both provinces, is less fissile in fresh exposures than the Noel to the west. The eastern black shale resembles closely parts of the typical Chattanooga and is probably in part equivalent to it. The proximity of land to the west seems to have resulted in considerable range in the age of the Mississippian Bachelor. Figure 4 shows a variety of relationships in the eastern central area.

In southeastern Missouri, as typified by Ste. Genevieve County, the Bushberg has not been identified with certainty. A hard, massive, conodont-bearing sandstone beneath the black shale occurs at the base of the upper Devonian at some places in this area. This sandstone and its fauna resemble most closely the Hardin of Tennessee. Typical relationships are shown in Figure 5.

Central Missouri

The "boundary formations" in the eastern part of the central Missouri area show the influence of the oscillating land boundary on that side of the province.

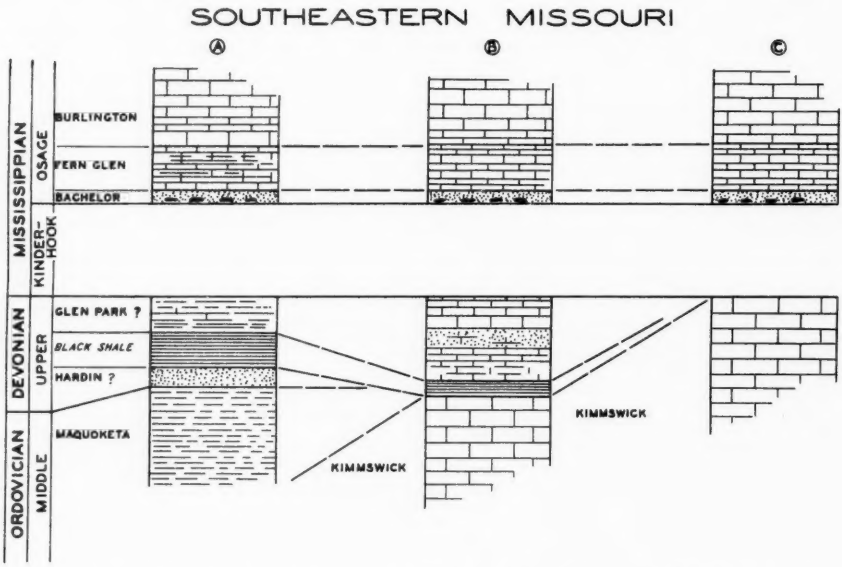

FIG. 5. Geological sections to show varied basal relationships of the Mississippian in Southeastern Missouri. Sections A and B are typical of Coal Hollow and Snell Hollow in Ste. Genevieve County. Section C may be duplicated in the northeastern part of this county.

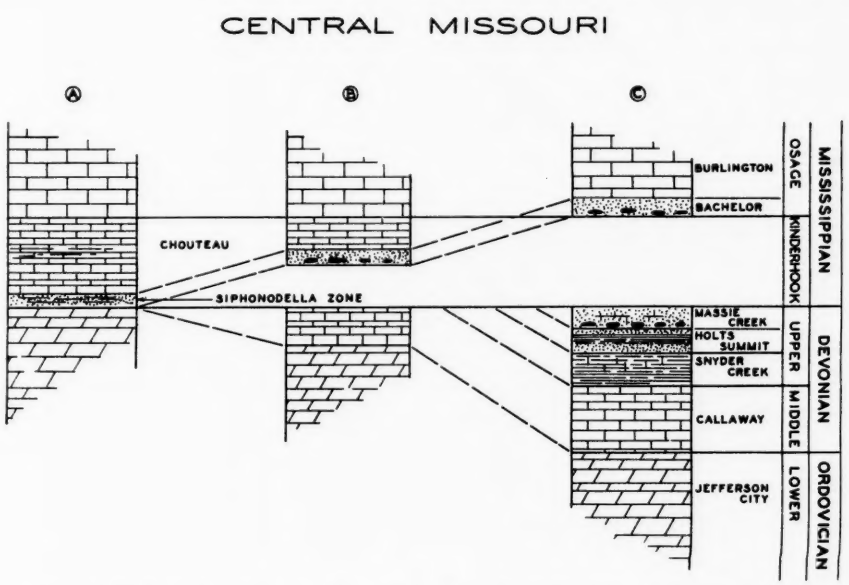

FIG. 6. Geological sections to show different basal relationships of the Mississippian in Central Missouri. Section A is typical of most of the central Missouri area. Section B is representative of northeastern Callaway County and in particular near the type locality of the Bachelor. Section C may be duplicated at the type locality of the Holts Summit in Callaway County.

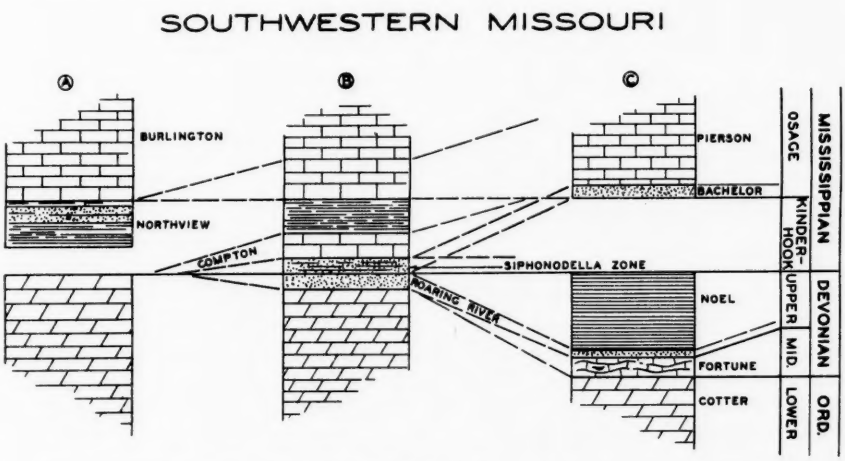

FIG. 7. Generalized relationships of the Mississippian in Southwestern Missouri. Section A is a common relationship in eastern Green County. Sections B and C may be duplicated in Barry County on Roaring River and east of Cassville, respectively.

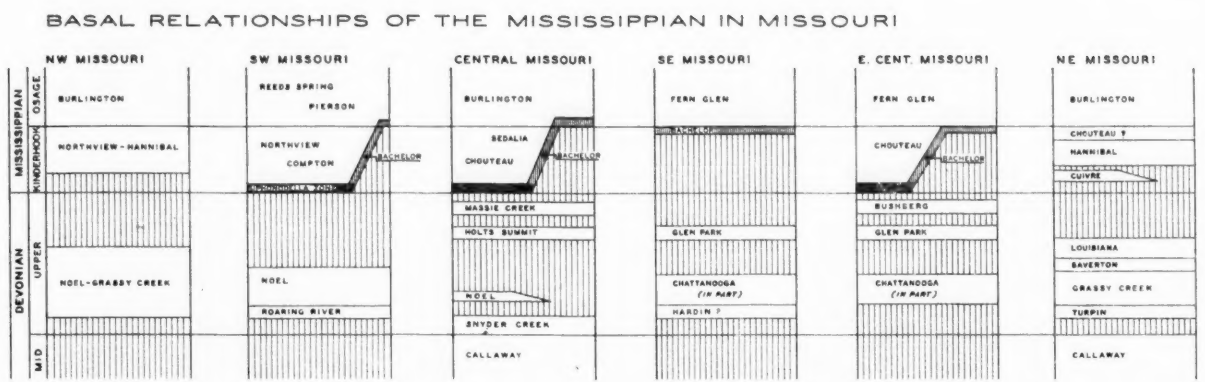

FIG. 8. Generalized regional geological sections to show the relationships of Devonian-Mississippian "boundary" formations. The Siphonodella Zone of the Bachelor is much more wide spread than the sections may suggest, and the younger part of the Bachelor is more limited.

The Massie Creek of this area occupies the same position as the Bushberg of the eastern provinces; and it is possible that the Holts Summit is the time equivalent of the Glen Park. In a few places thin patches of black shale are exposed; but it is not typical of the area. The basal Mississippian Bachelor varies in age from oldest to youngest Kinderhook. In the western part of the area the basal Mississippian is most commonly represented by the Siphonodella zone of the Bachelor, which rests on middle Devonian or older strata. Conventional relations of the province are shown in Figure 6.

Southwestern Missouri

Over most of the southwestern Missouri province the basal Mississippian is the Siphonodella zone of the Bachelor; but in limited areas the oldest Kinderhook is Bachelor of late Kinderhook age. Over a considerable area the Mississippian rests on Lower Ordovician dolomite. Elsewhere the Bachelor rests on the Upper Devonian Noel. The latter formation is represented in limited areas by the Roaring River sandstone member. Occurrences of Bachelor on Roaring River, Bachelor on Cotter (Ordovician), and outcrops of Roaring River, only, have constituted background material for the arguments concerning the identity and age of "Sylamore". Typical basal relationships of the Mississippian in this province are shown in Figure 7.

SUMMARY

The earliest Mississippian sea invasion of Missouri is recorded in a thickness of sandy clay or sandstone that, over most of its extent, measures less than one foot. The conodont fauna that characterizes this zone is sharply limited in time and does not extend to those areas that were not covered by the earliest part of the invasion. For this sand at the base of the Mississippian the name Bachelor is proposed. That part of the Bachelor to which the "oldest Mississippian" fauna is confined is designated as the Siphonodella zone. See Figure 8.

In Missouri the Mississippian rocks rest on a considerable variety of sediments that range in age from Lower Ordovician, through Silurian, to Upper Devonian. The Louisiana, Glen Park, and Bushberg are thought to be Mississippian by most stratigraphers. The Saverton, Grassy Creek, Noel and other "Black Shale" are thought by many to be entirely or in part Mississippian in age. All of these are designated as Devonian in this study.

With the above alignment of formations the conodont distribution evidence suggests that the faunal gap between the Mississippian and Devonian is one of the greatest in the Paleozoic column. A comparison of the distribution of key genera indicates that the earliest Mississippian strata in Europe and in North America are about the same age. However, the youngest Devonian strata in Central Europe are appreciably younger than those of North America.

New names are given to seven stratigraphic units as the best alternative to the application of names from one region to units of another region without sufficient evidence for such correlation.

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SOME LIMIT THEOREMS FOR ZEROS OF SUCCESSIVE DERIVATIVES

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1. *Introduction.* Let a function $f(z)$ be analytic in the complex plane. The zeros of this function form a set of points in the plane. If we pass to the zeros of the derivative $f'(z)$ we get, in general, another set of points; and if we continue the process through $f'', f''', \cdots$ we have a sequence of point sets formed by the zeros of successive derivatives of $f(z)$. Although it is meaningless to speak of the movement of any single point, it is of interest to study the trend of the successive point sets and particularly the limiting configuration.

For the class of entire functions of order less than one, Alander [1] showed that the zeros tend to scatter under repeated differentiation. In [2] Polya made some assertions about entire functions of finite order, but he gave no proofs. In this paper we present a unified treatment of these statements of Polya and show that the method used in the simple case by Alander may be applied to prove the stronger results. Further we show that this same method permits us to generalize to entire functions of arbitrary order.

2. *The Principle of Alander.* The method of Alander is based on the following principle:

Lemma 1: Let $a_1, a_2, a_3, \cdots$ be a sequence of non-negative numbers with the property that

$$\lim_{m=\infty} a_n = 0$$

Then there exists infinitely many indices n such that

$$a_n \geqq a_{n+p} \qquad (p = 0, 1, 2, \cdots)$$

These indices are said to be "principal".

Proof: If, from a certain one on, all $a_m = 0$, there is nothing to prove. Otherwise, let $a_{m_1} \neq 0$. Since $\lim a_m = 0$, there exists some index $n_1 > m_1$ such that

$$a_n < \tfrac{1}{2} a_{m_1} \tag{1}$$

for $n > n_1$. Now let a_μ be defined by

$$\begin{aligned} a_\mu &= \max a_m \\ m_1 &\leqq m < n_1 . \end{aligned} \tag{2}$$

If there is more than one a_μ satisfying (2) we choose the one with the largest subscript. In view of (2) and (1)

$$a_\mu \geqq a_{n_1} > a_n \qquad (n = n_1, n_1 + 1, \cdots)$$

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On the other hand

$$a_\mu > a_n \quad (n = \mu + 1, \mu + 2, \cdots, n_1 - 1)$$

by (2) and the fact that μ is as large as possible. Now let $m_2(>\mu)$ be a subscript corresponding to an a_i which is not zero. Applying our argument to

$$a_{m_2}, a_{m_2+1}, \cdots$$

instead of

$$a_{m_1}, a_{m_1+1}, \cdots$$

we obtain a new principal index greater than μ. Repeated application of the construction yields infinitely many indices.

The principle of Alander can now be applied in the following lemmas.

Lemma 2: Let $f(z) = \sum_{i=0}^{\infty} C_i z^i$ be an entire function of order $\lambda < \infty$. Then given $\alpha > \lambda$, there exist arbitrarily large integers n such that

$$| C_n | n^{n/\alpha} \geqq | C_{n+p} | \cdot (n + p)^{(n+p)/\alpha} \quad (p = 0, 1, 2, \cdots)$$

Proof: Since $f(z)$ is of order λ, its coefficients satisfy the relation

$$\overline{\lim_{n\to\infty}} \frac{n \log n}{\log \frac{1}{| C_n |}} = \lambda. \tag{3}$$

Set $\alpha = \lambda + \epsilon$, $\alpha' = \lambda + \epsilon/2$, $\epsilon > 0$, then (3) implies

$$| C_n | < \frac{1}{n^{n/\alpha'}} \qquad (n > N)$$

so that

$$| C_n | n^{n/\alpha} < n^{-(1/\alpha' - 1/\alpha)n}.$$

Hence

$$\lim_{n=\infty} | C_n | n^{n/\alpha} = 0$$

and we apply Lemma 1.

Lemma 3: Let $f(z) = \sum_{i=0}^{\infty} C_i z^i$ be convergent in $| z | \leqq R$ then for any constant A, $(0 < A \leqq R)$ there exists infinitely many indices n such that

$$| C_n | \geqq | C_{n+p} | A^p \qquad (p = 0, 1, 2, \cdots)$$

Proof: Since $f(z)$ is convergent in $| z | \leqq R$,

$$| C_m | A^m \to 0$$

hence by Lemma 1

$$| C_n | A^n \geqq | C_{n+p} | A^{n+p} \qquad (p = 0, 1, 2, \cdots)$$

and

$$|C_n| \geqq |C_{n+p}| A^p$$

3. *A Fundamental Lemma.* The sequence

$$\left\{\frac{(m+k)r^k}{k!(m+k^{(m+k)/\alpha}}\right\}_{k=1}^{\infty} \tag{4}$$

with m a positive integer, r and α positive real numbers, appears in many of the arguments that follow. We observe that the sequence converges to zero hence it must have a maximum term. The index k of the maximum term is called the *central index*, and we make the convention that if a number of terms are equal to the maximum term, the central index will be the index of the last of these equal terms. A fundamental property of sequence (4) is contained in

Lemma 4: Let $k = \nu$ be the central index of (4) where

(a) $m(\geqq 2)$ is fixed

(b) $r(<m^{1/\alpha})$ is fixed,

then

$$\nu \leqq \frac{mr}{m^{1/\alpha} - r}.$$

Proof: The central index ν is such that

$$\frac{(m+\nu-1)!r^{\nu-1}}{(\nu-1)!(m+\nu-1)^{(m+\nu-1)/\alpha}} \leqq \frac{(m+\nu)!r^{\nu}}{\nu!(m+\nu)^{(m+\nu)/\alpha}}$$

and

$$\frac{(m+\nu)!r^{\nu}}{\nu!(m+\nu)^{(m+\nu)/\alpha}} > \frac{(m+\nu+1)!r^{\nu+1}}{(\nu+1)!(m+\nu+1)^{(m+\nu+1)/\alpha}}.$$

Combining the inequalities, we have

$$\frac{\nu(m+\nu)^{(m+\nu)/\alpha}}{(m+\nu)(m+\nu-1)^{(m+\nu-1)/\alpha}} \leqq r < \frac{(\nu+1)(m+\nu+1)^{(m+\nu+1)/\alpha}}{(m+\nu+1)(m+\nu)^{(m+\nu)/\alpha}}.$$

Since $m \geqq 2$, the function

$$F(x) = \frac{(m+x)^{(m+x)/\alpha}\, x}{(m+x)(m+x-1)^{(m+x-1)/\alpha}} \qquad (x \geqq 0)$$

is continuous and $F(\nu) \leqq r < F(\nu+1)$. Hence, for any fixed $n \geqq 2$ and $r > 0$, there exists some ξ such that

$$r = \frac{(m+\xi)^{(m+\xi)/\alpha}}{(m+\xi)(m+\xi-1)^{(m+\xi-1)/\alpha}} \qquad (\nu \leqq \xi < \nu+1) \tag{5}$$

or

$$\xi = \frac{r(m+\xi)(m+\xi-1)^{(m+\xi)/\alpha}(m+\xi-1)^{-1/\alpha}}{(m+\xi)^{(m+\xi)/\alpha}}$$

$$= \left(1+\frac{\xi-1}{m}\right)^{-1/\alpha} \cdot \left(1-\frac{1}{m+\xi}\right)^{(m+\xi)/\alpha} \cdot \left(1+\frac{\xi}{m}\right) \cdot m^{1-1/\alpha} r.$$

Since $[1 - 1/(m+\xi)]^{(m+\xi)/\alpha}$ is monotone increasing to $e^{-1/\alpha}$ as $(m+\xi)$ increases, we may write

$$\xi < \left(1+\frac{\xi-1}{m}\right)^{-1/\alpha}\left(1+\frac{\xi}{m}\right) e^{-1/\alpha} \cdot m^{1-1/\alpha} \cdot r. \tag{6}$$

For fixed m and r, we now investigate inequality (6) so as to obtain a convenient bound for ξ in terms of r and m. To do this consider in (6), the term

$$\left(1+\frac{\xi-1}{m}\right)^{-1/\alpha}. \tag{7}$$

We observe three cases

(i) $\xi > 1$: clearly (7) is less than one.

(ii) $\xi = 1$: then (7) is equal to one.

(iii) $0 \leqq \xi < 1$: Since ξ is less than one, $\xi - 1$ is negative

and

$$\left(1+\frac{\xi-1}{m}\right)^{-1/\alpha} = \left(1-\frac{1-\xi}{m}\right)^{-1/\alpha} = e \exp -\frac{1}{\alpha}\log\left(1-\frac{1-\xi}{m}\right)$$

$$= e \exp \frac{1}{\alpha}\left(\frac{1}{1-\dfrac{1-\xi}{m}}\right)$$

$$\leqq e \exp \frac{1}{\alpha}\log\left(\frac{1}{1-\dfrac{1}{2}}\right) < e^{1/\alpha}$$

since $m \geqq 2$ and $\log(1/1-x)$ is monotone increasing for $0 \leqq x < 1$. Hence for any ξ, $(0 \leqq \xi < \infty)$ we may bound (8) by $e^{1/\alpha}$ and inequality (6) becomes

$$\xi < r\left(1+\frac{\xi}{m}\right) m^{1-1/\alpha}$$

or

$$\xi(1 - rm^{-1/\alpha}) < rm^{1-1/\alpha}$$

so that for $r < m^{1/\alpha}$ we have our result

$$\nu = [\xi] < \frac{rm^{1-1/\alpha}}{1-rm^{-1/\alpha}} = \frac{mr}{m^{1/\alpha}-r}.$$

4. *Univalent Derivatives.* In the study of zeros of successive derivatives of analytic functions, we are very much interested in regions which are free of zeros. Since the derivative of a univalent function has no zeros in the region of univalence, it is natural that our first theorem be concerned with such regions.

We start with a simple lemma which, though not explicitly stated, is a consequence of a known theorem [3, p. 200]. We state it without proof.

Lemma 5: Given $f(z) = \sum C_i z^i$ regular in $|z| < s$, then $f(z)$ is univalent in $|z| < s$ if

$$|C_1| > \sum_{k=2}^{\infty} k|C_k| s^{k-1}, \qquad (C_1 \neq 0) \quad (8)$$

Theorem 1: Given $f(z) = \sum C_i z^i$ entire of finite order $\lambda < \infty$, let S_m denote the radius of the largest circle entered at $z = 0$ inside of which $f^{(m-1)}(z)$ is univalent. Then

$$\overline{\lim_{m=\infty}} \frac{\log S_m}{\log m} \geqq \frac{1}{\lambda} - 1. \qquad (9)$$

Proof: If (10) is false, then

$$\overline{\lim_{m=\infty}} \frac{\log S_m}{\log m} < \frac{1}{\lambda} - 1$$

and it is possible to find a $\delta > 0$ such that

$$\frac{\log S_m}{\log m} < \frac{1}{\lambda + \delta} - 1$$

for all sufficiently large values of m, or equivalently

$$S_m < m^{1/(\lambda+\delta)-1} \qquad (10)$$

for all m large enough.

We now show that (10) leads to a contradiction. According to Lemma 5,

$$f^{(m-1)}(z) = \sum_{i=0}^{\infty} \frac{(m+i-1)!}{i!} C_{m+i-1} z^i$$

will be univalent for $|z| < \sigma$ provided

$$m!|C_m| > \sum_{i=2} \frac{(m+i-1)!}{i!} |C_{m+i-1}| \sigma^{i-1}.$$

Changing the summation index to $k = i - 1$, we have

$$m!|C_m| > \sum_{k=1} \frac{(m+k)!}{k!} |C_{m+k}| \sigma^k,$$

hence $f^{(m-1)}(z)$ will be univalent for $|z| < \sigma$ if $|C_m| \neq 0$ and

$$1 - \sum_{k=1} \frac{(m+k)!}{m!k!} \left| \frac{C_{m+k}}{C_m} \right| \sigma^k > 0, \qquad (|z| < \sigma) \qquad (11)$$

By Lemma 2 for $\alpha > \lambda$

$$| C_m | m^{m/\alpha} \geqq | C_{m+k} | (m + k)^{(m+k)/\alpha} \quad (k = 0, 1, 2, \cdots) \quad (12)$$

for infinitely many indices m. Let m be such a principal index. Now let $\sigma_m > 0$ be such that

$$1 - \sum_{k=1} \frac{(m + k)!}{m!k!} \cdot \frac{m^{m/\alpha}}{(m + k)^{(m+k)/\alpha}} \cdot {\sigma_m}^k > 0 \quad (13)$$

is true. Then (12) implies that (11) is true, with $\sigma = \sigma_m$, so that $f^{(m-1)}(z)$ will be univalent in every circle centered at the origin whose radius σ_m satisfies (13).

Now select ϵ_1, ϵ_2 such that

$$0 < \epsilon_1 < \epsilon_2 < \delta.$$

Then

$$m^{1/\lambda-1} > m^{1/(\lambda+\epsilon_1)-1} > m^{1/(\lambda+\epsilon_2)-1} > m^{1/(\lambda+\delta)-1}.$$

Let

$$r_0 = m^{1/(\lambda+\epsilon_1)-1}, \qquad \sigma_m = m^{1/(\lambda+\epsilon_2)-1}, \qquad (r_0 > \sigma_m) \quad (14)$$

and write (13) in the form

$$1 - \frac{m^{m/\alpha}}{m!} \sum_{k=1} \frac{(m + k)! {r_0}^k}{k!(m + k)^{(m+k)/\alpha}} \left(\frac{\sigma_m}{r_0}\right)^k > 0 \quad (15)$$

with $\alpha = \lambda + \epsilon_1$ (and $\beta = \lambda + \epsilon_2$) for convenience. Let $m > 2$; by definition, $r_0 < m^{1/\alpha}$, and we may apply Lemma 4 to the sequence

$$\left\{\frac{(m + k)! {r_0}^k}{k!(m + k)^{(m+k)/\alpha}}\right\}_{k=1}^{\infty}.$$

By this lemma

$$\nu < \frac{m^{1-1/\alpha} r_0}{1 - \dfrac{r_0}{m^{1/\alpha}}} = \frac{1}{1 - \dfrac{1}{m}}. \qquad (r_0 = m^{1/\alpha-1}) \quad (16)$$

Consider the auxiliary function

$$\varphi(\sigma_m) = \frac{m^{m/\alpha}}{m!} \sum_{k=1}^{\infty} \frac{(m + k)! {r_0}^k}{k!(m + k)^{(m+k)/\alpha}} \left(\frac{\sigma_m}{r_0}\right)^k \quad (17)$$

with σ_m, r_0 as defined in (14). Inequality (16) implies that the maximum coefficient in (17) is the first one ($k = 1$). In this case

$$\varphi(\sigma_m) < \frac{m^{m/\alpha}}{m!} \frac{(m + 1)! r_0}{(m + 1)^{(m+1)/\alpha}} \sum_{k=1}^{\infty} \left(\frac{\sigma_m}{r_0}\right)^k$$

$$< \left(\frac{m}{m + 1}\right)^{m/\alpha} \cdot (m + 1)^{1-1/\alpha} \cdot m^{1/\alpha-1} \cdot \frac{1}{m^{1/\alpha-1/\beta} - 1}$$

or, since

$$\left(\frac{m}{m+1}\right)^{m/\alpha} < 1, \qquad \varphi(\sigma_m) < \left(1+\frac{1}{m}\right)^{1-1/\alpha} \frac{1}{m^{1/\alpha-1/\beta}-1}. \tag{18}$$

Since $1/\alpha > 1/\beta$, we have for m sufficiently large

$$1 - \frac{\left(1+\frac{1}{m}\right)^{1-1/\alpha}}{m^{1/\alpha-1/\beta}-1} > 0$$

hence by (18)

$$1 > \varphi(\sigma_m).$$

This inequality is equivalent to (15). And if m is a principal index, this also implies (11) with $\sigma = \sigma_m$. We thus see that for such values of m, $f^{(m-1)}(z)$ is univalent in the disk

$$|z| < \sigma_m = m^{1/\beta-1}. \tag{19}$$

But in view of (10), σ_m should not exceed

$$m^{1/(\lambda+\delta)-1} < m^{1/\beta-1}.$$

This contradiction proves (9).

5. *Some Analogues and Corollaries.* Alander introduced his method to prove that if $f(z)$ is entire of order λ less than one and if ρ_m represents the modulus of the zero of $f^{(n)}(z)$ which is closest to the origin, then

$$\overline{\lim_{n=\infty}} \frac{\log \rho_n}{\log n} \geqq \frac{1}{\lambda} - 1.$$

An extension of this result is an immediate corollary of Theorem 1.

Corollary 1: Given $f(z)$ entire of order $\lambda < \infty$, and let ρ_m be defined as above, then

$$\overline{\lim_{n=\infty}} \frac{\log \rho_n}{\log n} \geqq \frac{1}{\lambda} - 1.$$

Proof: Since $\rho_n \geqq S_n$ the result follows.

We now make no assumptions on the order of an entire function $f(z)$ and ob tain three generalizations.

Theorem 2: Let $f(z) = \sum C_i z^i$ be convergent for $|z| \leqq R$; then

$$\overline{\lim_{m=\infty}} mS_m \geqq R \log 2, \tag{20}$$

where S_m is the radius of univalence of $f^{(m-1)}(z)$.

Proof: Assume the conclusion (20) is false; that is

$$\overline{\lim_{m=\infty}} mS_m < R \log 2.$$

Then there exists an $\epsilon > 0$ such that

$$mS_m < R \log (2 - \epsilon) \tag{21}$$

for all m sufficiently large.

We now show that this assertion leads to a contradiction. Since the series $\sum C_i z^i$ converges for $|z| \leqq R$ we apply Lemma 3; hence for infinitely many values of m

$$\left|\frac{C_{m+k}}{C_m}\right| \leqq \frac{1}{R^k}. \qquad (k = 0, 1, 2, \cdots) \tag{22}$$

Following the same argument as in Theorem 1, we note that $f^{(m-1)}(z)$ will be univalent for $|z| < \sigma \leqq R$ provided

$$1 - \sum_{k=1} \frac{(m+k)!}{m!k!} \left|\frac{C_{m+k}}{C_m}\right| \sigma^k > 0. \qquad (C_m \neq 0) \tag{23}$$

Let m be a principal index so that (22) is satisfied; let σ_m be such that

$$1 - \sum_{k=1} \frac{(m+k)!}{m!k!} \left(\frac{\sigma_m}{R}\right)^k > 0 \tag{24}$$

is true. Then (22) implies the truth of (23) with $\sigma = \sigma_m$, hence $f^{(m-1)}(z)$ will be univalent in every circle about the origin whose radius σ_m satisfies (24). But

$$1 - \sum_{k=1} \frac{(m+k)!}{m!k!} \left(\frac{\sigma_m}{R}\right)^k = 2 - \frac{1}{\left(1 - \frac{\sigma_m}{R}\right)^{m+1}}$$

so that (24) implies the univalence of $f^{(m-1)}(z)$ in every circle centered at $z = 0$ whose radius σ_m satisfies

$$\left(1 - \frac{\sigma_m}{R}\right)^{m+1} > \frac{1}{2}. \tag{25}$$

Now let

$$\sigma_m = \frac{R \log\left(2 - \frac{\epsilon}{2}\right)}{m+1}. \qquad (<R) \tag{26}$$

We show that this value of σ_m satisfies (25) for all sufficiently large principal indices m.

Substitute (26) into the left side of (25) gives

$$\left(1 - \frac{\sigma_m}{R}\right)^{m+1} = \left(1 - \frac{R \log\left(2 - \frac{\epsilon}{2}\right)}{R(m+1)}\right)^{m+1}$$

$$= \left(1 - \frac{\log\left(2 - \frac{\epsilon}{2}\right)}{m+1}\right)^{m+1}.$$

Since

$$\lim_{m=\infty}\left(1+\frac{\alpha}{m}\right)^m = e^{\alpha},$$

then

$$\lim_{m=\infty}\left(1-\frac{\log\left(2-\frac{\epsilon}{2}\right)}{m+1}\right)^{m+1} = \frac{1}{2-\frac{\epsilon}{2}} > \frac{1}{2}$$

so that, for all principal indices m, sufficiently large, (26) satisfies (25). But (26) implies

$$m\sigma_m = \frac{R\log\left(2-\frac{\epsilon}{2}\right)}{1+\frac{1}{m}}$$

which, for m large enough, exceeds

$$R\log(2-\epsilon).$$

As this contradicts (21) our theorem is proved.

Corollary 2: Given $f(z)$ entire, then

$$\overline{\lim_{m=\infty}}\, mS_m = \infty.$$

Proof: Since $f(z)$ is entire, R can be made arbitrarily large in Theorem 2, (20)

Corollary 3: Given $f(z)$ entire, then

$$\overline{\lim_{m=\infty}}\, m\rho_m = \infty.$$

6. *Zeros in the Unit Circle.* Using the principle of Alander, we now prove a theorem stated without proof by Polya [2, p. 181].

Theorem 3: Given $f(z) = \sum C_i z^i$ entire of finite order $\lambda < \infty$, let N_m be the number of zeros of $f^{(m)}(z)$ contained in the unit circle. Then

$$\overline{\lim_{m=\infty}}\,\frac{\log N_m}{\log m} \leqq 1-\frac{1}{\lambda} \qquad (\lambda \geqq 1) \quad (27)$$

and

$$\lim_{m=\infty} N_m = 0. \qquad (\lambda < 1) \quad (28)$$

Proof: Lemma 2 implies, for $\alpha = \lambda + \epsilon$, $\epsilon > 0$,

$$|C_n|\, n^{n/\alpha} \geqq |C_{n+k}|\,(n+k)^{(n+k)/\alpha} \qquad (k = 0, 1, 2, \cdots)$$

for infinitely many indices n. Let m be such a principal index. Then

$$\left|\frac{f^{(m)}(z)}{C_m m!}\right| \leqq \frac{m^{m/\alpha}}{m!}\sum_{k=0}\frac{(m+k)!r_0^k}{k!(m+k)^{(m+k)/\alpha}}\left(\frac{r}{r_0}\right)^k.$$

The Central index ν satisfies

$$\nu \leqq \frac{mr_0}{m^{1/\alpha} - r_0}$$

provided

$$r_0 \leqq m^{1/\alpha}, \qquad m \geqq 2.$$

We now let

$$r_0 = 1 + 2\delta \quad \text{and} \quad r = 1 + \delta. \qquad (\delta > 0)$$

Applying the same argument as in Theorem 1, we have for m sufficiently large

$$\left|\frac{f^{(m)}(z)}{C_m m!}\right| \leqq \frac{m^{m/\alpha}}{m!} \frac{(m+\nu)! r_0^{\nu}}{\nu!(m+\nu)^{(m+\nu)/\alpha}} \sum_{k=0} \left(\frac{r}{r_0}\right)^k$$

$$\leqq \frac{m^{m/\alpha}}{(m+\nu)^{m/\alpha}} \cdot \frac{(m+\nu)!}{m!(m+\nu)^{\nu/\alpha}} \cdot \frac{r_0^{\nu}}{\nu!} \left(\frac{1+2\delta}{\delta}\right) \leqq \frac{(m+\nu)^{\nu}}{(m+\nu)^{\nu/\alpha}} \frac{r_0^{\nu}}{\nu!} \left(\frac{1+2\delta}{\delta}\right)$$

since

$$\left(\frac{m}{m+\nu}\right)^{m/\alpha} < 1 \quad \text{and} \quad \frac{(m+\nu)!}{m!} < (m+\nu)^{\nu}.$$

Therefore

$$\left|\frac{f^{(m)}(z)}{C_m m!}\right| \leqq \frac{m^{\nu(1-1/\alpha)}}{\nu!} \left(1 + \frac{\nu}{m}\right)^{\nu(1-1/\alpha)} r_0^{\nu} \left(\frac{1+2\delta}{\delta}\right). \qquad (29)$$

We now assume until stated otherwise that $\lambda \geqq 1$, hence $\alpha > 1$, so that the central index ν satisfies

$$\nu < \left(\frac{r_0}{1 - \frac{r_0}{m^{1/\alpha}}}\right) m^{1-1/\alpha} < dm^{1-1/\alpha} < m \qquad (30)$$

where d is an appropriate constant and m is sufficiently large.

Consider the factors of (29). First, in view of the expansion of $e^{m^{(1-1/\alpha)}}$,

$$\frac{m^{\nu(1-1/\alpha)}}{\nu!} \leqq e^{m^{(1-1/\alpha)}} \qquad (\alpha > 1) \quad (31)$$

Further, from (30)

$$\left(1 + \frac{\nu}{m}\right)^{\nu(1-1/\alpha)} < \left(1 + \frac{\nu}{m}\right)^{\nu} < \left(1 + \frac{\nu}{m}\right)^{m} < e^{\nu}$$

hence

$$\left(1 + \frac{\nu}{m}\right)^{\nu(1-1/\alpha)} < e^{dm^{1-1/\alpha}}. \qquad (32)$$

Setting $(1 + 2\delta)/\delta = C$, and using inequalities (30), (31), (32) we have from (29)

$$\left|\frac{f^{(m)}(z)}{C_m m!}\right| < e^{km^{1-1/\alpha}} \cdot r_0^{dm^{1-1/\alpha}} \cdot C \qquad (k = d+1)$$
$$< (er_0)^{km^{1-1/\alpha}} \cdot C. \tag{33}$$

We now are ready to apply Jensen's Theorem [3, p. 125] which states that for a function $G(z)$ regular for $|z| \leqq R$

$$\frac{|G(0)|R^n}{r_1', r_2' \cdots r_n'} < \max_{|z|=R} |G(z)| \tag{34}$$

where $r_1', r_2', r_3', \cdots, r_n'$ are the moduli of the zeros of $G(z)$ contained in the circle $|z| = R$. Hence for $R = 1 + \delta$, if N_m represents the number of zeros of $f^{(m)}(z)$ in the unit circle, (34) yields

$$R^{N_m} < \max_{|z|=R} \left|\frac{f^{(m)}(z)}{C_m m!}\right|$$

or, by (33)

$$N_m \log R < Km^{1-1/\alpha} \log (er_0) + \log C. \tag{35}$$

Denote $(\log R)^{-1}$ by Q. Then (35) becomes

$$N_m < KQm^{1-1/\alpha} \log (er_0) + Q \log C$$
$$< m^{1-1/\alpha}\left[KQ \log (er_0) + \frac{Q \log C}{m^{1-1/\alpha}}\right]. \tag{36}$$

We take the logarithm of both sides of (36) and divide by $\log m$ to get

$$\frac{\log N_m}{\log m} < \left(1 - \frac{1}{\alpha}\right) + \frac{\log [\cdots]}{\log m}, \tag{37}$$

and letting m tend to infinity through suitable values yields the result (27).

If $\lambda < 1$, $(\alpha < 1)$ we have the simple argument:

$$\left|\frac{f^{(m)}(z)}{C_m m!}\right| \leqq \sum_{k=0} \frac{(m+k)!}{m!k!}\left|\frac{C_{m+k}}{C_m}\right| r^k$$
$$\leqq \sum \frac{(m+k)^k}{k!}\left(\frac{m}{m+k}\right)^{m/\alpha} \frac{r^k}{(m+k)^{k/\alpha}} \leqq \sum \frac{m^{k(1-1/\alpha)}r^k}{k!} = e^{m^{1-1/\alpha}r}$$

and (35) yields

$$N_m < Q' m^{1-1/\alpha}. \qquad \left(Q' = \frac{r}{\log r}\right)$$

The result (28) follows since the factor of Q' tends to zero.

Modifications of the above proof enable us to handle entire functions without regard for order. We obtain the following analogue of the preceding theorem.

Theorem 4: Given $f(z)$ entire, then

$$\lim_{m=\infty} \frac{N_m}{m} = 0$$

Proof: Using Lemma 3,

$$\left|\frac{f^{(m)}(z)}{C_m m!}\right| \leqq \sum_{k=0} \frac{(m+k)!}{m!k!}\left|\frac{C_m + k}{C_m}\right| r^k$$

$$\leqq \sum_{k=0} \frac{(m+k)!}{m!k!}\left(\frac{r}{A}\right)^k = \left(1 - \frac{r}{A}\right)^{-(m+1)}, \quad (r < A)$$

For $r > 1$, N_m, the number of zeros in the unit circle, (31) gives

$$N_m < (m+1)\frac{\log\left(1 - \frac{r}{A}\right)^{-1}}{\log r}$$

or

$$N_m < \left(1 + \frac{1}{m}\right)\frac{\log\left(1 - \frac{r}{A}\right)^{-1}}{\log r}$$

and since A can be taken arbitrarily large, the result follows.

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WEIGHTED RATIOS OF SUCCESSIVE DERIVATIVES

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In the study of problems related to the zeros of successive derivatives of an analytic function it is frequently convenient to investigate the behavior of sequences of ratios of successive derivatives in regions which are free to limit points of these zeros. In this paper we obtain an extension of a theorem due to Radstrom [2] pertaining to such sequences.

Edrei [1] proved the following.

Theorem A: Let $f(z)$ be regular in $|z| < |$ and $f \cdot f' \cdot f'' \neq 0$. If

$$\left|\frac{f'(0)}{f(0)}\right| > Ae,$$

then

$$\left|\frac{f''(0)}{f'(0)} - \frac{f'(0)}{f(0)}\right| < A \log\left(\frac{1}{A}\left|\frac{f'(0)}{f(0)}\right|\right)$$

where A is an absolute constant.

We will use Theorem A to prove

Theorem 1: Let $U(n)$ be a positive function tending to infinity with integral n. Assume that for z_0, not a limit point of zeros of successive derivatives of $f(z)$, that

$$0 < \underline{\lim_{n=\infty}} \frac{1}{U(n)} \left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| \leqq \overline{\lim_{n=\infty}} \frac{1}{U(n)} \left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| < \infty. \tag{1}$$

Then, for n sufficiently large,

$$\left|\frac{f^{(n+2)}(z_0)}{f^{(n+1)}(z_0)} - \frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| < \frac{C \log U(n)}{U(n)} \left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right|.$$

Proof: Let $f^{(n)}(z) \neq 0$ for $|z - z_0| < R$, $n > n_0$, and set

$$g(z) = f^{(n)}(z_0 + Rz).$$

Then $g(z)$ is regular for $|z| < |$ and

$$g(z) \cdot g'(z) \cdot g''(z) \neq 0. \qquad (\text{in } |z| < 1)$$

Now

$$\frac{g'(z)}{g(z)} = R \frac{f^{(n+1)}(z_0 + Rz)}{f^{(n)}(z_0 + Rz)}$$

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hence

$$\left|\frac{g'(0)}{g(0)}\right| = R\left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right|.$$

But hypothesis (1) implies

$$\frac{R}{A}\left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| > e$$

so that, by Theorem A,

$$\left|\frac{f^{(n+2)}(z_0)}{f^{(n+1)}(z_0)} - \frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| < \frac{A}{R}\log\left(\frac{R}{A}\left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right|\right).$$

Now (1) implies that there exist constants P, Q, both positive, such that for n large enough

$$PU(n) < \left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| < QU(n),$$

hence

$$\left|\frac{f^{(n+2)}(z_0)}{f^{(n+1)}(z_0)} - \frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| < \frac{A}{R}\log\left(\frac{RQU(n)}{A}\right) < \frac{A}{R}\frac{\log\left(A^{-1}RQU(n)\right)}{PU(n)}\cdot PU(n)$$
$$< \frac{C\log U(n)}{U(n)}\cdot\left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right|.$$

We note without proof that for $U(n) = n$, a slightly more precise theorem can be obtained by Radstrom's arguments, namely

Theorem 2: Let $f(z) = \sum a_i z^i$. If z_0 is not a limit point of successive derivatives of $f(z)$ and if

$$0 < \varliminf_{n\to\infty}\left|\frac{a_{n+1}(z_0)}{a_n(z_0)}\right| \leqq \varlimsup_{n\to\infty}\left|\frac{a_{n+1}(z_0)}{a_n(z_0)}\right| < \infty,$$

then

$$\left|\frac{f^{(n+2)}(z_0)}{f^{(n+1)}(z_0)} - \frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| < \frac{B}{n+1}\left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right|$$

where B is a constant.

However, the assumptions of this theorem severely restrict the class of functions to which the theorem can be applied. Theorem 1 is more flexible and applies to a larger class of functions. We now use Theorem 1 to prove

Theorem 3: Given z_0 as before, let $f(z)$ satisfy

$$0 < \alpha = \varliminf_{n\to\infty}\frac{1}{n^\gamma}\left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| \leqq \varlimsup_{n\to\infty}\frac{1}{n^\gamma}\left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right| = \beta < \infty$$

where $\gamma > 0$, then the sequence

$$\left\{\frac{1}{n^\gamma}\left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right|\right\}_{n=0}^{\infty} \tag{2}$$

has limit points everywhere in the interval $[\alpha, \beta]$.

Proof: Assume the result is not true. Then there are two numbers b, c $(b < c)$ inside the interval $[\alpha, \beta]$ such that no values of the sequence lie between them for n large enough. Consider two classes:

Class I: containing all values of (2) less than b.

Class II: containing all values of (2) greater than c.

Both classes contain an infinity of elements since otherwise either

$$\underline{\lim}_{n=\infty} \frac{1}{n^\gamma} \left| \frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)} \right| \geqq b \quad \text{or} \quad \overline{\lim}_{n=\infty} \frac{1}{n^\gamma} \left| \frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)} \right| \leqq c$$

which contradicts our assumption that b, c lie between these limits.

Moreover, Class II contains an infinity of elements

$$\frac{1}{n^\gamma} \left| \frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)} \right|$$

with the property that

$$\frac{1}{(n+1)^\gamma} \left| \frac{f^{(n+2)}(z_0)}{f^{(n+1)}(z_0)} \right|$$

belongs to Class I. This is true since if we assume only a finite number of elements of Class II with this property, then there is a greatest n such that the property holds. But then for some $m > n$,

$$\frac{1}{m^\gamma} \left| \frac{f^{(m+1)}}{f^{(m)}} \right|$$

belongs to Class II and so does

$$\frac{1}{(m+1)^\gamma} \left| \frac{f^{(m+2)}}{f^{(m+1)}} \right|$$

and so on, in which case Class I would not contain an infinity of elements.

Hence we have the existence of a sequence $\{n_\nu\}_{\nu=1}^{\infty}$ such that

$$\frac{1}{n_\nu^\gamma} \left| \frac{f^{(n_\nu+1)}(z_0)}{f^{(n_\nu)}(z_0)} \right| \text{ is in Class II}$$

and

$$\frac{1}{(n_\nu+1)^\gamma} \left| \frac{f^{(n_\nu+2)}(z_0)}{f^{(n_\nu+1)}(z_0)} \right| \text{ is in Class I}$$

or

$$\frac{1}{(n_\nu+1)^\gamma} \left| \frac{f^{(n_\nu+2)}(z_0)}{f^{(n_\nu+1)}(z_0)} \right| < b < c < \frac{1}{n_\nu^\gamma} \left| \frac{f^{(n_\nu+1)}(z_0)}{f^{(n_\nu)}(z_0)} \right|.$$

Hence

$$\frac{\dfrac{1}{n_\nu{}^\gamma}\left|\dfrac{f^{(n_\nu+1)}}{f^{(n_\nu)}}\right|}{\dfrac{1}{(n_\nu+1)^\gamma}\left|\dfrac{f^{(n_\nu+2)}}{f^{(n_\nu+1)}}\right|} > \frac{c}{b} > 1,$$

or

$$\frac{(n_\nu+1)^\gamma}{n_\nu{}^\gamma}\left|\frac{f^{(n_\nu+1)}}{f^{(n_\nu)}f^{(n_\nu+2)}}\right| > 1$$

for infinitely many n, n_ν.

On the other hand, Theorem 1 yields

$$\left|\frac{f^{(n+2)}(z_0)}{f^{(n+1)}(z_0)}\right| > \left|\frac{f^{(n+1)}(z_0)}{f^{(n)}(z_0)}\right|\left(1-\frac{C\log n^\gamma}{n^\gamma}\right)$$

or

$$\frac{1}{n^\gamma}\left|\frac{f^{(n+1)^2}}{f^{(n)}f^{(n+2)}}\right| < [n^\gamma - C\log n^\gamma]^{-1}.$$

Therefore

$$\frac{(n+1)^\gamma\,|\,(f^{(n+1)})^2\,|}{n^\gamma\,|\,f^{(n)}\cdot f^{(n+2)}\,|} < \frac{(n+1)^\gamma}{n^\gamma}\left(1-\frac{C\log n^\gamma}{n^\gamma}\right)^{-1}$$

$$< \left(1+\frac{1}{n}\right)^\gamma\left(1-\frac{C\log n^\gamma}{n^\gamma}\right)^{-1} < \frac{c}{b}$$

for n sufficiently large, since

$$\lim_{n=\infty}\left(1+\frac{1}{n}\right)^\gamma\left(1-\frac{C\log n^\gamma}{n^\gamma}\right) = 1.$$

For the case $\gamma = 1$, we have the result of Radstrom [2, p. 137].

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RESPONSE DECREMENT UNDER CONTINUOUS REINFORCEMENT AS A FUNCTION OF EFFORT

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Kendrick has recently reported the disappearance of a running response under continuous reinforcement. This finding verified a prior report by Calvin, Clifford, Clifford, Bolden and Harvey (1956) in which a less stringent extinction criterion had been exercised. It was decided to repeat the Kendrick study with slight changes in order to determine the generality of this phenomenon. A secondary consideration was the possible role of effort in producing extinction-like decrements in the running response. Runway length appeared to be a feasible variable for the manipulation of effort.

EXPERIMENT I

Apparatus

Two plywood runways, identical in all dimensions except length, were constructed. Inside dimensions were 3 in. wide, 3¾ in. high. One was 4 ft. long and the other 13 ft. long. The first foot of each served as the starting compartment. Both were painted flat black inside and out, and covered by a hinged lid of small mesh screen. The runways were placed on a stand 3½ feet high in the center of a windowless room measuring 9 ft. wide, 23 ft. long, and 8½ ft. high. Illumination was provided by two 300 watt unshaded incandescent bulbs each mounted in the ceiling 5 ft. from the ends of the room. The goal ends of both runways were under one of these bulbs. A transparent glass cup (1⅜ in. diameter, ¾ in. high) glued to the floor of the runway held the reinforcement.

Subjects

Twelve naive female albino rats aged approximately 90 days at the beginning of experimentation served as *S*s. Random assignment determined the runway in which *S* was trained. All *S*s were maintained in the animal colony room between experimental sessions under constant illumination with food continually present. All *S*s appeared healthy throughout the experiment.

Procedure

*S*s were placed on a watering schedule of 10 min. every 12 hrs., and habituated to handling for a period of seven days. The junior authors ran *S*s according to a random counterbalanced schedule of both *E*s and *S*s.

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Acquisition Period

During the first four days *S* was placed in the starting portion of the runway, the door was removed during orientation toward it, and *S* was allowed to drink for four sec. from the filled reinforcement cup in the goal area. *S* was then removed and immediately rerun. On day one AM, *S* received five trials and on day two AM, *S* received ten trials in order to maintain the deprivation schedule. At all other times *S* received 15 trials. One hr. after the last trial water was available for 10 min.; and the procedure was repeated in eleven hrs.

Asymptotic Period

During the fifth to seventeenth days inclusive, an identical procedure was followed, except reinforcement consisted of three drops of water placed in the cup by an eyedropper.

Recovery Period

For two weeks *S*s were maintained on a watering schedule of 20 min. each 24 hrs.

Retest Period

The procedure of the seventeenth day was repeated on one day, i.e., 15 trials in the AM and 15 trials in the PM.

Criteria

When *S*'s body (not including tail) was ¾ of its length out of the starting compartment a stop watch was started. The watch was stopped when *S* placed its head over the reinforcement cup and running time was recorded to the nearest second. At the end of two minutes an *S* that had not reached the reinforcement cup was removed from the runway and replaced in the start box with a 120 sec. trial recorded. This occurred once for one *S* on day one PM.

RESULTS

Asymptotic Period

Both groups conditioned rapidly, i.e., were apparently performing at an asymptotic level on days five to ten. The asymptotic running time of the long runway group was, as expected, higher than that of the short runway group (means of 3.84 and 1.16 sec., respectively). Because of the greater possibility for response variability the long runway group did not display as stable an asymptote as did the short runway group.

Beginning on day 11 AM and continuing to day 17 PM the long runway group ran consistently slower (mean of 6.06 sec.) than during days five AM to 10 PM (mean of 3.84 sec.). Since all *S*s exhibited response decrement the Walsh Test yielded a statistic significant at the .016 level. For the corresponding period there was no change in the asymptote of the short runway group.

Retest Period

Following the two week period during which no trials were given, all *S*s had lower running times when retested than immediately before the recovery period. Trial one of the day 18 AM was regarded as a warm-up, and not included in this retest data. The Walsh Test yielded a statistic significant at the 0.16 level for both groups. The mean of the long runway group was 3.29 sec. for day 18, and the mean of the short runway group was 1.00 sec. It should be noted that on day 18 AM *S*s were 20 hours deprived, while in the PM *S*s were only 11 hours deprived. Since the PM running time was lower than the AM running time it appears that the spontaneous recovery was not due to increased deprivation.

EXPERIMENT II

This experiment constituted a further attempt to replicate Kendrick's results by running *S*s once a day.

Apparatus

The apparatus of Experiment I was used with the addition of a titration pipette mounted on a ringstand for placing the two drops of reinforcement in the reinforcement cup. This allowed more efficient massing of trials.

Subjects

Thirteen naive female albino rats aged approximately 120 days at the beginning of experimentation served as *S*s. One *S* was discarded because it did not obtain a single reinforcement during the first two days of training. Random assignment determined the runway in which *S* was trained. All *S*s were maintained in the experimental room under constant illumination, with food continually present. All *S*s appeared healthy throughout the experiment.

Procedure

*S*s were placed on a watering schedule of 60 min. every 24 hrs. and habituated to handling. The junior authors ran *S*s according to a random counterbalanced schedule of both *E*s and *S*s.

Acquisition Period

On days one and two a procedure indentical to that of the first four days of Experiment I was followed, except that 15 trials were given each *S*.

Asymptotic Period

On days three to 42, each *S* received 30 trials, two drops of water per trial, and running time was recorded to the nearest $\frac{1}{10}$ sec. One hour after completion of the thirty training trials water was available for 60 min. A period of four days during which no training was given fell between the 39th and 40th days of this procedure. The regular watering schedule was maintained during these four days. On days 44 to 56 the latency between removal of the start box door and the

TABLE 1

Mean latencies and running times for the long and short runway groups at the end of experimentation

N = 6 in each group

Experimental Day Number	Long Runway Group		Short Runway Group	
	Latency (sec.)	Running time (sec.)	Latency (sec.)	Running time (sec.)
44	99.3	5.63	24.5	1.35
45	41.2	4.13	10.1	1.25
46	67.7	5.15	17.0	1.29
47	120.1	8.17	22.5	1.50
48	60.8	4.61	7.6	1.23
49	73.5	5.28	4.2	1.20
50	35.8	4.84	5.5	1.20
51	59.0	4.20	5.5	1.20
52	42.8	3.84	8.7	1.30
53	57.5	5.24	2.3	1.40
54	102.1	5.03	1.0	1.30
55	112.6	7.21	3.5	1.48
56	126.5	6.07	5.1	1.25

animal leaving the starting compartment was also recorded to the nearest second.

Recovery Period

For 15 days *S*s were maintained on a watering schedule of 60 min. each 24 hrs.

Retest Period

The procedure of day 55 was repeated, i.e., 30 massed trials.

RESULTS

Both groups conditoned rapidly, i.e., were performing at an asymptotic level on day five (means of 4.82 and 1.21 sec. for the long and short runway groups, respectively). After 55 days of running *S*s there was no indication of decrement, except on the part of *E*s. The retest data obtained after 15 days of no running was essentially identical to that obtained before the recovery period.

The latency recorded between removal of the start box door and *S* leaving the starting compartment showed no systematic trends for the long runway group, but the short runway group appeared to be consistently improving. This latency was considerably greater for the long runway group than for the short runway group and is summarized in Table 1. The magnitude of the differences is so large that analysis was regarded as unnecessary. For comparsion, the running times for these days are also given.

DISCUSSION

It is appparent that under the given conditions *S*s display greater resistance to extinction than do *E*s.

The occurrence of spontaneous recovery for both groups in Experiment I is puzzling in view of Kendrick's (1958) report of no recovery for completely extinguished animals. Spontaneous recovery would appear to suggest the presence of a mechanism other than conditioned inhibition.

The complete failure to obtain any evidence of response decrement in Experiment II leads to speculation concerning the variables which produce such decrement. Kendrick reported that the first *S* to reach his extinction criterion did so on day 19, and the last on day 42 (with a mean of 33.20 days). Thus, the present *S*s of Experiment II were run 13 days beyond the time at which all of Kendrick's *S*s had extinguished. One theoretically meaningful variable which differed between the two studies was runway height and width. Kendrick's runways were 6 in. wide and 10 in. high, rather than 3 in. wide and 3¾ in. high as in the present study. Narrow runways should interfere with extinction because they interfere with the occurrence of competing responses. However, during the preparation of this manuscript there appeared Fuchs' (1960) reported failure to obtain decrements with a duplication of Kendrick's runway. Fuchs' replication leads to speculation concerning the interpretation of the phenomenon of response decrement under continuous reinforcement. If the phenomenon is so sensative to minor changes in experimental conditions as to be virtually unreproducible, its theoretical importance appears to be virtually nil.

The results of Experiment II indicate that the role of effort should be investigated further, and special attention should be directed toward start box latency.

In a critical review which appeared during the preparation of this manuscript (Prokasy, 1960) the need for determining the role of various experimental variables in producing decrement during continuous reinforcement has been stressed. The present report also indicates the need for replication in psychological research.

SUMMARY AND CONCLUSIONS

In an attempt to determine the role of effort (as manipulated by runway length) in producing response decrement under continuous reinforcement, two experiments were conducted. In Experiment I there was found some evidence that decrements occur, but no such evidence was found in Experiment II.

The urgent need for replication in psychological research was pointed out.

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ABSTRACTS OF HONORS PAPERS

Presented by Members of the Graduating Class of 1960
Denison University

Presented herewith is a list of Seniors of the Class of 1960, arranged in alphabetical order, who qualified for graduation "with Honors" in part through the presentation of acceptable theses on assigned topics in their major field.

The sponsoring Department and the Adviser in each case are indicated, the title and an abstract of each thesis submitted are given. Copies of the complete theses are available in the University (Doane) Library.

THE IMMEDIATE AND LASTING EFFECTS OF AMPHETAMINE SULFATE ON LEARNING IN THE WHITE RAT

WILLIAM BENNETT, JR.

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Department of Psychology

This experiment was designed to study both the immediate and lasting effects of amphetamine on learning in the white rat. It was inspired by the contradictions apparent in the previous research that has been done with amphetamine and behavior. As the problem appears to be partly a methodological one, it is felt that this paper also has something to say about behavioral variables in general.

Nineteen male albino rats (10 experimental and 9 controls) learned 12 variations of the Hebb-Williams free field maze. The experimental animals learned the first six patterns under amphetamine; the controls received a saline. Following a sixteen day waiting period, all animals learned the second six mazes with no injections. Finally, all animals were submitted to experimental extinction.

Three different analyses of the data (errors and times) collected on the drug period all allowed for rejection of the null hypothesis at better than the .02 level. Therefore, the experimental hypothesis, that amphetamine would interfere with complex performance, was upheld. In the retest period there was some graphical indication that the formerly drugged animals reversed their position, *sic.* outperformed the controls; but the differences were not statistically significant. The data for extinction showed the experimental animals to have a greater resistance to extinction.

A tentative conclusion from the study, and its comparison with past research, is that amphetamine, a stimulant when described physiologically, retards performance as the task becomes more complex; that is, as the performance becomes less reliant on physical conditions and more reliant on "learning". Another

interesting result of the study is the interaction between learning under the drug and resistance to extinction. It occurs to the experimenter that the internal stress condition induced by the drug *may* be complimentary to the stress induced by the frustrating experience of extinction and thereby may act to increase resistance.

THE LEGAL STATUS OF LABOR UNIONS IN THE STATE OF OHIO

JASON BLACKFORD

Adviser: Leland J. Gordan
Department of Economics

There are two legal forms that labor unions in the state of Ohio have been able to assume—a corporation or a voluntary association. The corporate form was available to unions by an act of the state legislature prior to the adoption of the Constitution of 1851. The courts of Ohio have also construed that an amendment passed on May 1, 1872, to the Ohio Corporation Code permitting the incorporation of life insurance companies may apply to labor unions. The major reason for this interpretation is that many labor unions were also engaged in providing insurance for their members. In 1935 the legislature nullified this interpretation by prohibiting any labor union to incorporate. The National Trades Union Act of 1886 was an attempt by Congress to permit trade unions to incorporate under Federal sanction. Since few unions ever incorporated under this statute, and since there was considerable misuse of the statute, the measure was repealed in 1932.

There are several reasons why labor unions wished to incorporate. First, the unions hoped to gain acceptance in the eyes of management by the fact that the union was legally responsible for its actions. Second, incorporation of unions limited the liability of the individual member in any tort or breach of contract committed by the union. Employers desired unions to incorporate so that unions would be responsible for the acts of their members or so that the corporate status would permit employers to bring an action to a union for damages and thereby attach union funds. Some employers hoped to use this power to attach union funds as a weapon to "break" unions.

All other labor organizations that are not incorporated are considered to be voluntary associations which at common law are not suable. In 1851 the General Assembly passed a bill that permitted a representative suit against large unincorporated associations or, in other words, a plantiff was permitted to join a group with a common interest to an action. This is a principle of equity that has been made to apply to non-equity actions.

In the United Mine Workers of America v. Coronado Coal Company case the Supreme Court determined that a voluntary association could be joined to an action. This was later codified into the Federal Rules of Civil Procedure as Rule 17 (b). Therefore, either under the representative suit section of the Ohio Code or the Coronado decision as codified in Rule 17 (b), a voluntary association is suable.

Federal legislation, such as the Federal Anti-Injunction Act, the National Labor Relations Act, the Labor-Management Relations Act and the Labor-

Management Reporting and Disclosures Act, have altered the legal procedure of joining labor unions to suits but has not fundamentally changed the legal status of labor unions. The advent of federal legislation has created definite problems of whether the state or the federal government should control the status of labor organizations. The trend is definitely toward Federal control and regulation.

THE AUDEN GROUP OF POETS AND THE GREAT BRITAIN OF THE NINETEEN THIRTIES

ROBERT H. CANARY

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Department of History

The dominant critical approach to Auden, Spender and Day Lewis is to consider them as uniquely related to their immediate historical environment. The conclusion of this study was that the dominant critical approach overstates the case.

A concern with social and policical matters is a distinctive feature of the poetry of Auden, Spender and Day Lewis, but it is not as important as it is distinctive. Unemployment, poverty, and the rise of Fascism made them peculiarly sensitive to social issues. The failure of Labor in power and the rise of the Soviet Union made them sympathetic towards Communism. However, they never had a very clear notion of the principles of Marxism and, when they did use them in their poetry, mixed Marxism with psychoanalysis. Disillusionment with Communism after the Spanish Civil War and the horror of the approaching war drove their political views from their poetry.

The course these poets followed was typical of many young British intellectuals of the decade.

They tried to influence their times by reaching the public with light verse and drama. They failed.

THE STUDY OF A SOLVENT OF POSSIBLE USE IN NUCLEOPHILIC REACTIONS INVOLVING IODIDE IONS AND ORGANIC HALOGEN COMPOUNDS

ANNE F. CODE

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A study of the rates of reaction of sodium iodide with n-butyl chloride in 2-butanone as the solvent (as compared with the corresponding rates of the same reaction in acetone) was made at various temperatures.

The reaction methods and analytical procedures were carried out following the methods of J. B. Conant and W. R. Kirner. Specially purified acetone, 2-butanone, n-butyl chloride, and sodium iodide were used in this work.

Sodium iodide reacts with n-butyl chloride in a bimolecular, nucleophilic

substitution reaction and occurs in the following manner:

$$Na^+I^- + CH_3(CH_2)_2CH_2Cl \xrightarrow{(acetone)} \underline{Na^+Cl^-} + CH_3(CH_2)_2CH_2I$$

By determining the amount of iodide ion that has not reacted with the n-butyl chloride at fixed time intervals, the reaction rates were calculated, assuming second order kinetics. The analysis of the amount of sodium iodide remaining was done by titration with potassium iodate in the presence of excess hydrochloric acid.

Analysis of the reaction occurring in acetone and with the reaction occurring in 2-butanone at three different temperatures showed that the rate of reaction of n-butyl chloride and sodium iodide was greater in 2-butanone than in acetone. Accordingly, the rate constant, k, for the reaction in 2-butanone at 40°C. is 0.0574 liters/mole hour: at 50°C., 0.154 liters/mole hour: at 60°C., 0.401 liters/mole hour. And in comparison, the rate constant for the reaction in acetone is 0.0467 at 40°C., 0.120 at 50°C. and 0.3 at 60°C.

It is suggested that the increase in rate of reaction of n-butyl chloride with sodium iodide in 2-butanone at a given temperature is due to a decrease in the polarity of this solvent in comparison with acetone and a corresponding decrease in the energy of activation. Continued research with other higher homologs of acetone may reveal compounds that will permit a still faster reaction to occur. This would have the practical advantage of allowing certain halogen-containing organic compounds, which have been found to react extremely slowly with sodium iodide in acetone as a solvent, to react at an increased rate. Also it would permit reactions to be carried out at temperatures well above 56.2°C. (the usual boiling point of acetone) without the use of special pressure equipment. This, of course, would give correspondingly higher reaction rates.

ELEMENTS OF EARLY GERMAN NATIONALISM AS REFLECTED IN NINETEENTH CENTURY LITERATURE

GARDNER G. DEMALLIE JR.

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Nationalism, as it was formulated in Germany under the impact of Napoleon's conquest and occupation, consisted of a strange amalgam of disparate ingredients. Because Germany lacked the reality of political, religious, economic or even territorial uniformity, the proponents of early German nationalism were forced to emphasize those few elements of nationhood, mainly cultural, which Germans did have in common. Intellectuals turned nationalists spread among the German people nationalistic and dynamic concepts which reawakened in them a consciousness of the real and also imaginary ties uniting all Germans. In these efforts German intellectuals expressed themselves in newspapers, pamphlets and essays, and furthermore exploited literature to convey their message. And since Germans have traditionally been receptive to poetry, the writings of the period in this genre especially served to make Germans become conscious of themselves as

Germans, their cultural unity, their national homogeneity and consequently their right to national independence.

In the attempt to arouse this dormant national feeling in Germany, the writers stressed a combination of beliefs which reappears constantly in the literature from the beginning of the nineteenth century to the Wars of Liberation in 1813. Most German authors during this period skillfully used and propagated traditional German nationalistic doctrines. Among them and foremost was the propagandistic exploitation (and occasional perversion) of a just desire for liberty from Napoleonic rule and freedom for the German nation. There was a like exploitation and perversion of thoughts rooted, sometimes tenuously, in religious soil—as nationalists sought to instill a religious enthusiasm in their compatriots for the sacred cause of national independence. Hatred of the enemy became a virtue as writers skillfully magnified the traditional enmity between France and Germany. Nationalists conjured with physical environmental features such as the Rhine and the oak tree, seeking to develop in their countrymen a sentimental attachment to the German land. They elevated the German language to the status of a national cultish bond. This concern with language was but one expression of the nationalists' basic general interest in everything intrinsically native or national, manifested in the championing of the *Volk*, their lore, traditions, and folk literature. And finally, the writers romanticized a common past as an inseparable link between all Germans. Though none of these propagandistic devices originated in reaction to Napoleon (all had a long tradition in the culture of Germany and had aroused the German people in the past), the force of their expression, a new emphasis, an added meaning for the German population because of its political prostration, and the skillful combination of these old elements—formed a new brand of German nationalism.

Although other factors existed that went into the makeup of this complex phenomenon, these, as revealed in the literature of the time, received the greatest stress. A reasonable conclusion, then, would be that these elements primarily stimulated and constituted the new German nationalism.

GANDHI AND TOLSTOY, A STUDY OF POLITICAL ACTION AND LITERATURE

DIANE DOWNS

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This essay is presented with a dual purpose: to distinguish the pacifism of Gandhi from that developed by Tolstoy and to explain a similarity in the mature thought of these two men. The general thesis is based upon a distinction between the concepts of compassion and pity. Pity implies such close emotional identification with its object that the pitying person has little ability to act rationally in aid of his cause. Compassion involves a harmony with suffering which still re-

mains at a distance from that very suffering. Such compassion is a necessary component of both effective social action and good literature.

Gandhi's religion is one of ultimate generalities tempered and given personality through an extreme emphasis on individual interpretation. The individual interpretation fluctuates constantly between self-denial and the requisites of an active life among mankind. The ascetic refusal to become emotionally involved with the world allows the actor to stand at a compassionate distance from his object.

Since he believed that truth is apparent in all things, Gandhi constantly compromised to achieve the most truth from every facet of life. Viewing the world from a detached position, Gandhi is able to recognize the truth within everything. Satyagraha, Gandhi's non-violent and organized method of gaining political ends, is born of the Indian's belief in compassionate compromise. In an idealistic and unbounded general situation, satyagraha was never wholly successful; in specific situations it often achieved its aims.

Tolstoy passed through two phases. His mature and compassionate literary intuition stood apart from the life it considered. Tolstoy did not believe in the freedom or efficacy of organized group action; he wrote of the expansion of the individual consciousness to achieve a certain personal freedom and joy. But Tolstoy's own fear and guilt pushed him to a second phase where he grasped at an unqualified belief in a pacifistic and fundamentalist interpretation of the teachings of Christ. The later Tolstoy felt that his art must transmit the feeling of the brotherhood of all men. The author's pitying identification with the evils and woes of all mankind translates itself into the ranting, sarcastic sermons which mar Tolstoy's later writings. *Resurrection* alienates its reader as it preaches this brotherhood. For the author of *Resurrection* is consumed by an ineffective and self-conscious pity.

Gandhi's was an effective and organized non-violence, formulated within a compassionate context. Tolstoy's pacifism was completely individual and passive. In their mature intuitions, both Gandhi and Tolstoy reached a compassionate acceptance of the validity within all things. Gandhi finds the most complete realization of the individual as a segment of truth through individual self-restraint, involving a certain subjugation of the senses. Tolstoy, as he writes in the great novels, finds the same relationship to life in the joyful, unquestioning acceptance of that life.

INTERNATIONALISM VERSUS NATIONALISM AS REFLECTED IN THE FORMATION AND OPERATION OF THE COUNCIL OF EUROPE

MARITA DRACH

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The concept of a united Europe is centuries old. From the time of the Roman Empire, to the development of the modern dynastic state and Henry IV's

"Grand Design," through the interim period between World War I and World War II with its League of Nations, up to the recent period of history which saw the establishment of organizations such as the Benelux, and NATO, the idea of a united world, and more specifically, of a united Europe has appealed to men's imaginations. Nationalism, however, has acted as a counter-balance to this desire for unity and the spirit of internationalism. It has been the prevailing force which has repeatedly hindered the attempts to create a supranational European community which have been made in the last two decades by visionary "Europeans," who have sought to achieve such unity in order to rebuild a war-crippled Europe and maintain a strong community which could stand firmly in the face of the Russian threat.

In accordance with the concept of European unification the Council of Europe, an organization first proposed in the 1948 meetings of the Brussels Treaty Organization, was created, and met for the first time in August, 1949, in Strasbourg. It was felt by many of the first delegates to the Council of Europe that the Council would develop in such a way as to provide an effective international political framework for the economic, social and political integration of Western Europe.

When the Council was established in 1949 it was composed of two bodies, the Assembly, which was the elected or appointed representative body for the member states, and the committee of Ministers, made up of the foreign ministers of the fifteen member countries.

In order to bring the idea of European integration into actual practice the Assembly of the Council struggled to play a significant role in European affairs from 1949–1956. Time after time the Assembly's most important programs, such as the Strasbourg Plan, or the creation of a European Agricultural Authority under the auspices of the Council, failed to be activated. Resolutions and recommendations advocated by the Assembly which would have furthered European unity were predominately ignored by the Committee of Ministers. Of the many reasons for these failures certainly the most significant was the persistence of nationalism, first as it influenced the delegation of power in the Council, as established by the Statute of the Council of Europe, and second, as it influenced the diplomatic actions of France, Germany, and most especially, Great Britain.

The Council of Europe, as it emerged as a functioning organism, was merely a confederation possessing powers of deliberation and recommendation only. It was not, and has not become, a parliament of a supergovernment.

After examining the available evidence one is forced to conclude that the Council of Europe has made no real progress towards European federation. The Assembly in recent years has ceased to issue elaborate and specific proposals for unification and now couches any such proposals in broad terms which can be examined as desired by the member governments themselves. Any specific economic programs or the furthering of political federation seems to have fallen now into the hands of such organizations as the European Coal and Steel Community (ECSC), Euratom, or the Organization for European Economic Cooperation (OEEC).

The Council of Europe appears to be an increasingly less effective body, and due primarily to the tenacious spirit of nationalism on the part of member nations its chief functions have now become merely those of discussion, suggestion and the commendation of any progress towards unity which might have been achieved by the other international organizations.

A COMPARATIVE STUDY OF WALLACE STEVENS' *NOTES TOWARD A SUPREME FICTION* AND T. S. ELIOT'S *FOUR QUARTETS*

JAMES GALLANT

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The fundamental distinction drawn between T. S. Eliot and Wallace Stevens as poets in this essay is between Eliot's mystical type of poetic contemplation on the one hand and Stevens's working theory of the imagination on the other.

In the chapter on *Notes Toward a Supreme Fiction* by Stevens, a distinction is drawn between two types of imaginative activity which Stevens sets up in the poem, one called imposition and the other discovery. The two overlap at a number of points and the relationship is a difficult one. The type of imagination which is most apparently at work in the creation of *Notes* itself is the discovering type of imagination. This is the speculative imagination as opposed to the willful, personal, practical imagination, which is imposition.

Stevens achieves a sense of reality by means of his theory of the imagination, and so that sense depends upon his own vision. The sense of the totality of things, grasped imaginatively, amounts to the "fiction of an absolute" or the "supreme fiction," which is the subject of the poem. It is the poet himself who is the "absolute" consciousness of this imaginative world.

Eliot's approach to poetry is not one in which the organization of experience and ideas is individualistic in Stevens' sense. Nor is it really an organization at all. Eliot stresses the "extinction of personality" and seeks not a unique, individualized organization of ideas and experience, but for a sense of reality which excludes the self from any determining role. Ideas are valuable to him because they are the means by which he collapses all being in all time into a oneness in contemplation. And such oneness is Incarnation, the co-existence of the eternal and the temporal.

Eliot's sense of the totality of things is mystical. The unity of being in his scheme of things depends upon intense moments of experience, the perfection of which the poet desires to carry over to every moment. Stevens's sense of the totality of things depends upon imaginative discovery by the individual consciousness and has rather more to do with conscious activity, as such, than Eliot's oneness.

A STUDY OF THE CYCLE NOVEL *JEAN-CHRISTOPHE* BY ROMAIN ROLLAND

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It is impossible to cite *all* of the people and forces that had an influence upon Romain Rolland. It is possible, however, to mention several of them. In *Journey Within*, Rolland mentions three sources of inspiration of his youth—Nature, Spinoza and Tolstoi. As a young man, Rolland met Malwida von Meysenburg who had considerable influence on his philosophies. Three other sources of inspiration were Beethoven, Michelangelo, and Tolstoi, to whom Rolland has paid tribute in the *Vies Héroiques*.

The structure of the novel *Jean-Christophe*, as well as the creation of the characters, bears a definite relationship to these sources of inspiration. These sources reflect a sensitive and reflective nature in Rolland by the very fact that he chose them and not less impressive ones. His treatment of them is worthy of their value.

The dominant themes, too, reflect the philosophies that were impressed upon Rolland. His use and developement of them adds significantly to the stature of this cycle novel.

ELIZABETH I: THE ART OF PUBLIC RELATIONS

FREDERICK C. GIFFIN

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The author has attempted to demonstrate that the conscious cultivation of popular support was a crucial factor in Elizabethan politics. Foremost in Elizabeth's mind was the desire to rule as well as reign. To achieve this desire she relied upon the arts of the master politician, keeping constantly in tune with the murmur of public opinion. The skill with which she handled her public relations is indicated by an analysis of her conduct before parliament, her frequent progresses, and her attempt to use the press as an instrument in cultivating royal popularity. Examples of the various techniques evident in the Queen's conduct have been included to illustrate the specific nature of her quest for support.

COMPARISON OF PHOSPHORUS-32 AND COLORIMETRIC METHODS IN THE DETERMINATION OF BLOOD VOLUMES

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The determination of total blood volume of an animal has long been the object of much investigation. Many methods have been tried, but there was little

success until 1935, when Evans blue, a diazo dye, was used. Its main advantages were its low toxicity and the ease with which the dye concentration may be read on a colorimeter.

Evans blue dye has been the most widely used substance for determining blood volume. However, it is known to have a number of drawbacks which may affect the validity of the results. Recently, a new method using radioactive phosphorus-32 has been under investigation.

The purpose of this series of blood volume determinations was to compare the results obtained using the Evans blue dye and the phosphorus-32 methods simultaneously. Five experiments were performed, using a dog as the experimental animal.

There were not enough data to prove definitely the superiority of one method over the other, since some of the results were invalid due to known experimental errors. However, the experiments do indicate that the phosphorus-32 method consistently gave more reliable figures than did the dye method. Although blood volume determination by the phosphorus-32 method requires more care in handling of radioactive materials, the procedure seems to offer fewer sources of error than other methods. However, further experimentation is necessary for proof of accuracy.

SOCIAL INFLUENCE: EFFECTS OF GROUP SIZE AND METHOD OF INFLUENCE PRESENTATION UPON MELODIC VALUING

WILLIAM H. HEID

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Past research in social influence has worked with two main classes of variables. The first has included the conditions or variables of the experimental group setting and the second has included the personal conditions of the subject which enter from outside the group setting. The study of group conditions has allowed the formation of generalizations concerning the important variables within the social influence situation. Two which have been shown to be critical are the size of the interacting group and the method of influence presentation.

The hypotheses for the present study included the following. The subjects will reverse their judgments of melodic quality more often when presented with information concerning the judgments of other group members than when this information is not presented. The subjects will reverse their judgments more often when the influence information consists of each of the other individual's judgments than when the information presents only the concensus or normative judgment of the rest of the group. The subjects will reverse their judgments more often within an influence group of seven members than within an influence group of three members. When group size and type of influence are combined, there will be an additive effect building more effective and less effective total influence group conditions.

One hundred and thirty-five students of introductory psychology were divided

into six kinds of groups. They judged twice the comparative quality of nine pairs of melodies. For the influence groups, influence information was presented before each pair of melodies during the second series of judgments. The control groups received no influence information. The data for each subject were the total number of reversals of judgments and the percentage of actual to possible reversals on selected pairs of melodies.

The results of the study gave support for the prediction of a general influence effect according to both the complete and selective treatments of the data. The second prediction was only supported slightly except that a selection of data showed no significant difference between the normative type of groups of three and the control groups. The prediction for size was shown with numerical differences but the only significant statistic was the difference between the larger groups of individual type influence and the smaller groups of normative type. This last difference was the main support for the prediction of an additive factor in that the more effective type of influence combined with the more effective group size produced the largest number of reversals while a combination of normative type influence and small size produced the least reversals.

It was concluded from the results that a social influence effect can be found with musical judgments. Further, it was thought that combinations of variables must be more clearly understood in relation to the interactions and compounded effects of a complex situation. It was suggested that the areas of aesthetics and values are perhaps the best opportunity for the study of social influence and its complex dimensions.

A STUDY OF THE ATTITUDES OF HIGH SCHOOL SENIORS TOWARD INTERNATIONAL RELATIONS

STEPHANIE JENKINS

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This project was devoted to studying the opinions of high school seniors and the relationship of their opinions to other socio-economic and personality variables.

The methodology employed in studying international attitudes was that of constructing an international Value Scale and subsequently testing and comparing it to other variables. The Value Scale consisted of ten statements about international affairs. The students were to express their degree of agreement or disagreement with the statements, and those who were strong in agreement were considered to have high international values. Along with the Value Scale, an Expectation Scale was constructed for measuring the students' expectations of future world co-operation possibilities. The Value and Expectation Scales were included with the Adorno Scale and several minor items in a questionnaire which was administered to Newark Catholic High School and Granville Public High School seniors.

The results of the study were these: (1) Granville High School was found to

be more internationalistic than Newark Catholic High School, but other differences between the schools, rather than religion, may have caused this difference in values, (2) men were found to be more internationalistic than women, and (3) children of professional men were found to be more internationalistic than children of skilled laborers. It was also found that (1) those who were high in values were also high in international expectations and (2) those who were high in ethnocentrism were low in Values.

Thus, this study attempted to determine what international opinions these students hold and how their opinions are related to socio-economic and personality variables.

AN ANALYSIS OF COMMON STOCK PRICE FORECASTING

JACK C. KERN

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This paper discusses and analyzes the two basic approaches—fundamental and technical—to common stock price forecasting. The discussion and analysis are aided by a study of several prominent forecasting methods with respect to their classification within the basic approaches. Some of the methods analyzed are the Dow Theory, Odd-Lot Index, Security Analysis, Technical Analysis and news forecasting. However, all the methods analyzed are used primarily to illustrate and evaluate the technical or fundamental approach to forecasting.

In addition, the results of a questionnaire study of the judgments of twenty-two brokers, with regard to which of the two approaches is the more valid and reliable, are reported. The accuracy achieved by professional forecasters as presented in several studies conducted by the Cowles Commission is reviewed. These studies tend to indicate that professional forecasters have not, on the whole, shown an ability to accurately predict either the action of the market or the individual stock. However, an evaluation of the manner in which the studies were conducted reveals that the results therefrom are likely unsound and disputable.

Finally, the author expresses his own judgments as to the best means of common stock price forecasting by concluding that both approaches should be used in predicting the action of an individual issue. Greater emphasis should be placed on the fundamental in the selection of a "long-term growth" issue while the technical approach seems to be more valuable in "short-term" forecasting. It is also concluded that the technical approach appears to be vastly superior to the fundamental in forecasting market action as a whole.

A STUDY OF THE REACTION OF DIETHYL CHLOROMETHYL-PHOSPHONATE WITH ALCOHOLIC SODIUM ETHOXIDE IN THE PRESENCE AND ABSENCE OF WATER

HOWARD KIDD

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Department of Chemistry

The reaction of diethyl chloromethylphosphonate (I) was studied, in the presence and absence of water, to learn more about this particular phosphorus compound.

In the reaction of (I) with alcoholic sodium ethoxide in the presence of water, one mole of compound (I) reacted with slightly more than three equivalents of the alkali, and the reaction was complete after 8 hours of refluxing. The graphs constructed from the data of several electro-metric titrations of the reaction mixture after varying lengths of time suggest that reaction occurs at three points on the molecule, $Cl—CH_2—P(O)(OC_2H_5)_2$. If this is true, an ether linkage would probably form at the chlorine position, and two —ONa groups would attach to the phosphorus atom in place of the two ethyl ester groups, due to saponification. The proposed equation would then be:

$$Cl—CH_2—P(O)(OC_2H_5)_2 + 3\ NaOC_2H_5 \xrightarrow[\text{water}]{\text{alcohol}} H_5C_2—O—CH_2—P(O)(ONa)_2 + 2\,(H_5C_2)_2O + NaCl$$

It was shown that compound (I) is thermally stable, that chloride ions are definitely produced in the reaction, and that three equivalents of alkali react with one mole of compound (I) when water is present. Therefore, this proposed equation seems to be a logical conclusion.

In the anhydrous reaction, only slightly more than one equivalent of sodium ethoxide reacted with one mole of compound (I). The graph constructed from electrometric titration data appears to be a typical acid-base neutralization curve. Therefore, reaction is probably only occurring at the chlorine position on the molecule. The graph, then, merely shows the neutralization of the excess alkali. It is suggested that, if reaction had occurred at either of the ester groups on the molecule, a second break would have occurred in the titration curve, as in the aqueous reaction, due to neutralization of the reaction product. Chloride ions were also shown to be produced in this reaction. Therefore, if the proposals are correct, the equation in the absence of water would be:

$$Cl—CH_2—P(O)(OC_2H_5)_2 + NaOC_2H_5 \xrightarrow[\text{anhydrous}]{\text{alcohol}} H_5C_2—O—CH_2—P(O)(OC_2H_5)_2 + NaCl$$

Attempts were made to recover the product of this reaction, namely $H_5C_2—O—CH_2—P(O)(OC_2H_5)_2$; but decomposition appeared to be occurring during recovery processes. With a slight modification in procedures, which is suggested in the paper, it probably will be possible to isolate this compound to aid in proving the validity of the proposed equation.

A STUDY OF THE BETA AND GAMMA FUNCTIONS AND THEIR APPLICATIONS TO MATHEMATICS AND STATISTICS

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Department of Mathematics

The gamma function, $\Gamma(n)$ is defined by the improper integral

$$\Gamma(n) = \int_0^\infty x^{n-1}e^{-x}\,dx \qquad \text{for } n > 0.$$

This definition is extended to $n < 0$ by the recurrence formula $\Gamma(n+1) = n\Gamma(n)$. $\Gamma(n)$ is discontinuous for $n = 0, -1, -2, -3, \cdots$.

The beta function $B(m, n)$ is defined by the improper integral

$$B(m, n) = \int_0^1 x^{n-1}(1-x)^{n-1}\,dx \qquad \text{for } m, n > 0.$$

$B(m, n)$ is continuous for all $m, n > 0$. Its similarity to $\Gamma(n)$ is shown in the relationship

$$B(m, n) = \frac{\Gamma(m)\Gamma(n)}{\Gamma(m+n)}$$

Other forms of both $\Gamma(n)$ and $B(m, n)$ are indicated.

The paper is a study of the properties of the beta and gamma functions and of their application to mathematics and statistics. Included are evaluation of some definite integrals which are non-integrable in terms of elementary functions; the Dirichlet Integral; Stirling's Formula for the approximation of n-factorial; and Wallis's Product, an infinite product for $\pi/2$.

Applications of the beta and gamma functions to statistics including the Beta and Gamma Distributions, their cumulative distributions and moment generating functions, are discussed.

CHOREOGRAPHY OF *THE BACCHAE*, A EURIPIDEAN PLAY; A LECTURE-DEMONSTRATION IN MODERN DANCE

LYNNE KOTHERA

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Department of Theatre Arts

This honors project included the choreography and performance of the Theatre Arts Department's production, *The Bacchae* by Euripides, and the presentation of a lecture-demonstration. The written project is in the form of a journal, or at least it is written in such a way as to indicate the activity prior to choreography as well as the difficulties involved in the choreography. It must be clearly understood that the brevity of the paper is unavoidable simply by the very nature of the project. That is, there is no way of discussing intelligently the hundreds of

hours spent in the studio, improvising and creating. It is not readily understood that hour after hour can be spent on creating a few seconds of movement, and then more hours to perfect the movement.

Not all of my ideas materialized; there were many dead ends. But I learned a good deal in spite of those failures. Much time is needed for selection of a workable idea and suitable music. What may seem to be a profound thought and appropriate music may not prove to be at all practical. Finally my research created a curiosity about the body and the heterogeneous mixtures of bodies which people the environment.

PERSONALITY VARIABLES AND SUSCEPTIBILITY TO SOCIAL INFLUENCE

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Social influence research in the past has attempted to understand the complex processes involved in the social formation of personal preferences. Many studies have uncovered individual differences which appear to be related to personality factors. This study has tried to isolate and measure three of these factors and relate them to measured judgment reversals in a musical situation.

The relationships between specific personality variables (musical talent, self-adjustment, and anxiety level) and reversals of melodic judgments under conditions of social influence have been measured with 135 introductory psychology students.

Specific hypotheses predicted that measured self-adjustment and measured anxiety level are both positively correlated with reversal of melodic judgment under influence conditions. Further, it was predicted that measured musical talent is negatively correlated with musical judgment reversals under non-influence conditions; that this negative correlation will be altered with the introduction of social influence conditions; and that alteration will vary with the extent of influence.

The Spearman rank correlation resulted in no significant relationship between anxiety level and judgment reversals although the predicted direction was shown. The self-adjustment and judgment reversal correlation for the total influence group supported the predicted relationship. Further statistical treatment showed some inconsistency in specific groups. All three predictions for the musical talent and judgment reversal relationship were significantly supported: the total group correlation for the control conditions, the difference between this and the total influence correlation, and the varying differences between this total control correlation and varying levels of influence effectiveness.

Several things have been concluded from this study. Specifically it seems that anxiety level has little relationship with musical judgments in a non-anxiety producing social influence situation. Self-adjustment appears to be an important

factor in the understanding of individual differences in susceptibility to social influence. Musical talent, as a measure of specific competence, is found to be highly related to consistency of musical judgments except when persons of high talent are exposed to social influence pressures. In the latter situation, there seems to be a tendency toward a positive relationship between talent and susceptibility.

It is finally concluded that personality variables cannot be ignored in a study of social influence or any related area. The problems of complexity and individual differences must be met in future research.

A STUDY OF NON-EUCLIDEAN GEOMETRY

DELMA JUNE MILLER

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Department of Mathematics

Any study of Non-Euclidean Geometry will be concerned with four questions: What is Non-Euclidean Geometry? How did it develop? What are its principal characteristics? How are these characteristics used in problems?

Non-Euclidean Geometry is the name given by Carl Friedrich Gauss to a logical consistent geometry in which the Fifth Postulate in Euclid's *Elements* is denied. In the nineteenth century Non-Euclidean Geometry was discovered almost simultaneously by three men after centuries of attempts to prove the Fifth Postulate which states:

> If a straight line falling on two straight lines make the interior angles on the same side less than two right angles, the two straight lines, if produced indefinitely, meet on that side on which the angles are less than two right angles.

Johann Bolyai, a Hungarian, and Nikolai Ivanovich Lobachewsky, a Russian, both published their findings of the new geometry, while Gauss, a German, did not make public his results. Thus the discovery of Non-Euclidean Geometry is generally accredited to Bolyai and Lobachewsky, although others contributed to its development.

There are two types of Non-Euclidean Geometry, Hyperbolic Geometry and Elliptic Geometry. The characteristic postulate of Hyperbolic Geometry reads:

> Through a given point not on a given line, more than one line can be drawn not intersecting the given line.

In Elliptic Geometry the characteristic postulate is stated: Two straight lines always intersect one another.

One of the dominant figures in Non-Euclidean Geometry is the Saccheri Quadrilateral, drawn by constructing equal perpendiculars on the same side at each endpoint of a line segment and then joining the endpoints of these equal perpendiculars. In Hyperbolic Geometry it can be proved that the sum of the angles of every triangle is less than two right angles, while in Elliptic Geometry the sum of the angles of every triangle is greater than two right angles.

Such properties as these are a part of the set of postulates, definitions, theorems, and corollaries which is employed in the analysis of problems in Non-Euclidean Geometry. It is the act of using these properties to obtain solutions to problems which emphasizes for the student of mathematics what Charles Sanders Pierce said in 1870: "The essence of mathematics is the study of what is true of hypothetical states of things."

CROSS RESISTANCE OF *ESCHERICHIA COLI* AND *MICROCOCCUS PYOGENES AUREUS* TO VARIOUS ANTIBIOTICS AND SURFACE ACTIVE AGENTS

JAMES E. MILLER

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Using gradient plate and serial dilution techniques, cultures of *Escherichia coli* and *Micrococcus pyogenes aureus* have been made resistant to the following antibacterial agents: cetyltrimethylammonium bromide, a cationic surface active agent; sodium lauryl sulfate, an anionic surface active agent; and the antibiotic penicillin. Subsequently, the sensitivity of each strain was tested against all of the agents listed above in addition to chloramphenicol. Varying degrees of cross resistance between the surface active agents and the antibiotics were observed. The development of resistance and the role of altered permeability of the cell wall in drug resistance are discussed.

A WORLD OF CONTROL: THE NOVELS OF JANE AUSTEN

KRISTINE OTTESEN

Adviser: Kenneth B. Marshall
Department of English

The purpose of this Honors Project is to demonstrate, through an analysis of six of her works, that in Jane Austen's novels artistic control parallels and conveys the presence, quality and effects of social control in the lives of her characters.

In *Northanger Abbey* control by absurd social standards and romantic notions is presented and qualitatively paralleled by the devices of exaggeration, antithetical balance and irony. The limiting framework of parody in the novel prevents full and subtle use of artistic control.

The self-control of the main character is excessive in *Sense and Sensibility*; and she is led to impose her standards of extreme self-command on others, violating their natural dispositions. The novel fails because of the lack of any clearly-defined, consistently employed technique of artistic control, excepting vague and undeveloped symbols of Sense and Sensibility.

Pride and Prejudice contains figures who attempt to control their futures and those of other characters through carefully-plotted schemes. The attempt is

shown to be irrational and unnatural through the use of recurrent diction patterns or "word centers" of Design and Reason/Nature. Jane Austen's artistic control becomes explicit in relation to the importance control assumes in each character's life and the obviousness with which his attempts to control are manifested.

The deterministic control exerted by persons and environments over the formation of character is illustrated in *Mansfield Park*, and shown to be insurmountable. The artistic control parallels the increasing exposition of deterministic control through the repetition of a major diction pattern, Propriety, and smaller related word centers in application to action and character at three levels of meaning.

Emma centers on the development of one figure, whose desire to control other people is a product of her social, economic, and intellectual position in a small community; she is expected to exert influence. The disadvantage of this "gift" of control must be recognized and overcome. Emma Woodhouse is described ironically so long as she is not fully aware of the folly of accepting and practicing such control. The use of irony as a form of artistic control declines in proportion to her gradual enlightenment.

Persuasion is filled with characters who are controlled by words which have lost their significations; names, ranks, and physical descriptions, especially, become independent values beyond which people are incapable of perceiving. A word center composed of these kinds of words, Arbitrary Measurement, through the pattern in which it occurs, opposes interest and disinterest in these words as values in themselves, and illustrates their meanings when they actually accomplish their linguistic purpose of signification.

In each novel Jane Austen shows that the desire to control the lives of others is an irrational, unnatural, dehumanizing force fruitlessly destined to turn back on itself, and that such a force can be surmounted only by sincere human relationships and rational consideration of others.

PROJECTIVE GEOMETRY: TWO APPROACHES TO INVOLUTION

SUE JANE PERROTT

Adviser: Chosaburo Kato
Department of Mathematics

This paper is a study of projective transformation. Projectivity is defined as a chain of perspectivities, showing that cross ratio is invariant under this transformation. Projectivity is dealt with on a line and on a conic.

A conic is determined by two projective pencils as the locus of intersections of corresponding lines, and dually; that is, a conic is also considered as the envelope of lines joining corresponding points of two projective point rows.

Involution is a projectivity of period two. The study of projectivity, with special regard to involution, is made both synthetically and analytically.

Analytically, the conic is taken in the form

$$x_1 = t^2, \qquad x_2 = 2t, \qquad x_3 = 1,$$

where the values t_1, t_2 are determined by the points in which the line $(ux) = u_1 \cdot x_1 + u_2x_2 + u_3x_3 = 0$ of the pencil of lines $(ux) + t(vx) = 0$ cuts the conic given by the intersections of the pencils

$$(ax) + t(bx) = 0$$

$$(cx) + t(dx) = 0$$

Lines of the pencil intersect this conic in two points, thus giving two values of t, and defining involution.

This paper is an attempt to organize material gathered from various sources, to bridge gaps and revise proofs of some of the theorems, and to solve problems.

THE SEARCH FOR IDENTITY: AN ANALYTICAL THEMATIC STUDY

DIANE TORGLER

Adviser: Dominick P. Consolo
Department of English

Since it is the nature of man to try to find order in the universe and since the elements of experience do not carry within them principles of connection and organization, meaningfulness of existence implies a source and end beyond itself. Thus every moral act is grounded in and points toward an ultimate perfection not capable of being realized in any human situation. Man has ever been confronted with the problem of reconciling human weakness with his notion of the ideal. Reinhold Niebuhr, in *An Interpretation of Christian Ethics*, says that meaningfulness of life comes from the insistence on the "organic relation between historic human existence and that which is both the ground and fulfillment of this existence, the transcendent." (p. 99).

In accordance with these basic premises, six American novels have been chosen for their relevance to the basic theme of the search for the self and its relation to the physical world.

There has been great emphasis placed on this search in the last sixty years because the faith that man has had in man has been destroyed by two world wars, a great depression and much suffering. The power of man to direct his actions toward worthy ends has been seriously challenged.

As a result of the disillusionment in the progress of the world, modern literature expresses a deep pessimism. It is filled with violence, perversion, ugliness and despair. On the other hand, within the framework of these harsh realities, a subtle optimism is expressed.

The following six novels are to be examined: *Lie Down in Darkness*, *The Great Gatsby*, *All the King's Men*, *Corpus of Joe Bailey*, *The Catcher in the Rye*, and *Other Voices Other Rooms*.

Each novel stresses the need for a meaningful existence in its definite expression that reality stems from a belief that the problems of the world will never be answered by an ideal, but that by holding the ideal as source and end beyond

human existence, the threat of chaos does not destroy the hope of the search for identity. Reality is neither the self nor the physical world but a relation between the two, a realization that the ideals a man holds as absolute can never be fully attained in this world, yet are inherent in every act.

A STUDY OF JACK KEROUAC AND THE BEAT GENERATION

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Briefly, this paper has as its thesis two main ideas. One is that the beat generation is worthy of serious consideration as a dynamic force in modern American literature and culture. The other idea is that Jack Kerouac is the main figure of this movement and that he is a writer of serious intent and high talent. The method used in studying Kerouac has been to look at him in light of his literary predecessors, Henry Miller and Thomas Wolfe; to study the reviews of and comments on his writing; to look at his novels individually.

This paper is largely opinion, but opinion supported by evidence. The body of the paper is in three sections. The first of these deals mainly with beat poetry and with general discussion of the beat generation. The second section concerns the idea of rebellion and a study of the ancestors of the beats. The third section is Kerouac. This section represents well over half of the paper, and therefore I would not recommend this paper for anyone just interested in "beats in general." The bibliography is annotated in an attempt to spur interest.

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